HIGH ALTITUDE AERIAL PHOTOGRAPHY FOR THE INTERPRETATION OF AGRICULTURAL LAND USE

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by

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ABSTRACT:

Agricultural land use in the Niagara Peninsula was examined using high altitude colour infrared aerial photography obtained from aircraft. A visual analysis of the photography revealed that it contained great detail, and that the hue and density of the images were especially important in the interpretation process. In the subsequent densitometric investigation, it was found that quantified image density alone was of limited value in land use recognition, due to the density distortion inherent in the photography. The numerical data were much more useful when the ratios of densities in two emulsion layers of the film were determined, since this procedure largely removed the distortion element.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

1.1 Aim of the Study

The general increase in population and the expansion of urban areas have stimulated the need for the evaluation and planning of agricultural resources. Aerial photography is an excellent tool for the inventory of rural land use, since it provides timely information over substantial areas of the earth's surface. In recent years, small scale photography has been employed for agricultural surveys. Its extensive areal coverage at a small scale decreases the time required for handling and analysis, as well as the costs involved.

At present, methods are being sought to improve the precision of photographic analysis and to reduce the time needed to examine broad regions. Working generally with image density, these methods are directed towards automatic or semi-automatic interpretation, through the use of quantitative remotely sensed data and various statistical techniques.

In keeping with the present trend in agricultural analysis, the current investigation is concerned with the use of high altitude aerial photography for the inventory of rural land use.

Orbital photography recorded from spacecraft has been widely examined for agricultural purposes; however, high altitude photography flown from aircraft has very rarely been used. This lower flying height has a number of technical and economic advantages over the higher one from space. In consequence, the present investigation seeks to evaluate the suitability of the high altitude aircraft sensing package for the interpretation of agricultural land use.

It is realized at the outset that high altitude photography has a characteristic distortion of image density that is not related to the ground surface. This distortion factor presents complications in the process of photographic interpretation. As a further problem in this study, therefore, a simplified means of reducing the degree of distortion is sought, in order to improve the interpretive value of the image density.

1.2 Photography

The photography used in this project was available through the Canada Centre for Remote Sensing (CCRS) in Ottawa. The missions on which the photography was flown were conducted on August 4, 1972 and September 10, 1973. A flight had also been planned for July of 1973; however, the images that it produced were unsuitable for the investigation.

Vertical aerial photography was obtained using a Wild RC-10 camera with Kodak Ektachrome Infrared Aero film, Type 2443, and a Wratten Number 12 yellow haze filter. Lenses of different focal lengths were used in the two flying operations, a 3.5 inch lens being used in August and a 6 inch lens being used in September. The flying heights during the missions were sufficient to produce aerial photography at a nominal scale of 1:60,000.

1.3 Area of Study

The northern part of the Niagara Peninsula was selected as a suitable area for the current investigation. This region of Southern Ontario is a very important producer of agricultural goods in the province. Its general location is illustrated in Figure 1.1

The area of study is characterized by intensive agricultural and urban land use along the shore of Lake Ontario, with the major farm products being tender tree fruits and grapes. Proceedings southward in the direction of Lake Erie, the rise in elevation caused by the Niagara Escarpment is accompanied by a change in soil and climate. As a result, there is a reduction in the frequency of orchards and vineyards, and pasture and fodder crops for livestock operations become more prevalent.

The Niagara Peninsula is well suited for the present study in many respects. Perhaps the most important factor is related to the quantity and variety of agricultural land uses in the area. There are many fields of the same land use, allowing a representative sample to be examined for each type, and also allowing the variability within each type to be considered. There are also many fields of different types of land use, making it possible to analyse the variations among them and the usefulness of the sensing package for their differentiation.

Secondly, the area has been covered by many recent flying missions using the high altitude colour infrared sensing package, and ground information regarding rural land use has been collected on some of these occasions. Thus, photography obtained in August of 1972, long before this study was proposed, could be used in conjunction with the September 1973 photography for comparative purposes.

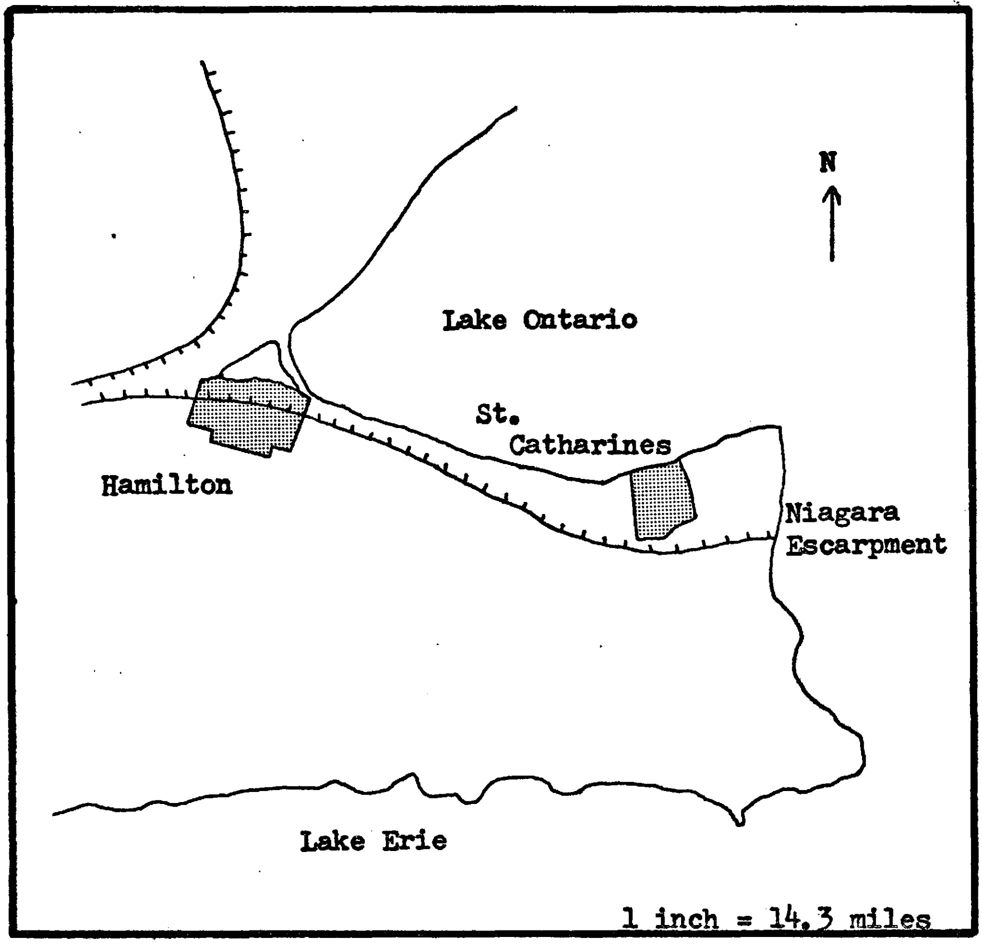


Figure 1.1 The Niagara Peninsula

As another favourable factor, the area lies close to McMaster University and the author's residence, making the attainment of real or near-real time ground information an easy and inexpensive task.

Finally, the author's basic familiarity with the region, its farming methods and operations was helpful in the planning aspects of this project, and should be of value in the interpretation of the photography.

1.4 Outline of the Thesis

The ensuing discussion is concerned with the use of high altitude colour infrared photography flown from aircraft for the study of rural land use in the Niagara Peninsula. An initial chapter presents a review of the literature pertaining to agricultural land use studies from aerial photography. Beginning with the earliest published material, the changes in the type of remotely sensed information and in the methods of interpretation up to the present time are examined.

Chapter Three considers the nature of the photography in detail. This type of background information is essential before a comprehensive interpretation can be carried out. Included in the chapter are a discussion of the film and the photographic platform, their values and their limitations, as well as theimage characteristics that are important in interpretation and the sources of variation in the image density characteristics over the photograph.

The two subsequent chapters concern the investigations undertaken in the present study. The first one describes the visual interpretation of the photography, while the second deals with the quantitative study. This latter phase involves an examination of the nature of image density distortion and the efforts taken to remove it.

The final chapter in the report summarizes the entire paper and presents the conclusions reached in the investigation. It also includes some recommendations for future study that have become apparent in the work which has been undertaken.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Remote sensing has only been employed in agricultural studies for approximately twenty years. Although aerial photographs were used as early as 1934 by the United States Department of Agriculture, their first significant applications to crop and land use inventory did not begin until the late 1950's with the work of Goodman (1959).

These initial investigations involved the interpretation of rural land use from medium scale black and white aerial photography. While the photographs proved to be a valuable source of information, the amount of detail they provided was limited. In the next decade, therefore, research was primarily concerned with the development and evaluation of specialized sensors and techniques of interpretation. With the vast amount of data which have become available from these developments, there has arisen a need for automated or partially automated methods of interpretation. It is along these lines that much research is now directed.

The following review of literature concerning the application of aerial photography to crop and land use surveys will be divided into the three categories implied above. The first will consider the use of medium-scale panchromatic photography; the second, the more specialized techniques of remote sensing; and the third, the development of automatic or semi-automatic means of interpretation.

2.2 Conventional Panchromatic Photography

Early investigations into the use of air photographs in agriculture attempted to identify various crops or crop types, and to determine the photographic characteristics that were helpful in interpretation. The photography at the time was generally flown at a medium scale of 1:10,000 to 1:20,000. Panchromatic film was used, yielding black and white images covering most of the visible spectrum (from 0.4 to 0.7 μ).

Earliest studies revealed that different types of rural land use, as well as individual species of crops, could be recognized on aerial photographs (Brunnschweiler, 1957; Goodman, 1959). Photographic tone, texture and stereoscopic vision were the most important factors in the interpretation process, although other elements, such as shape, size and shadow, were also of some value. Later work showed that the use of working and planting patterns, and knowledge of local farming practices, could significantly increase the amount of detail and precision that were attainable (Erb, 1968; Wood, 1968). Wood, for example, placed heavy reliance on the types and dates of various farming operations and field patterns in his interpretation of agricultural land use in Southern Ontario. As he commented in a more recent article, "ordinary black and white photographs can reveal much new information if the air photo interpreter knows enough about his subject" (Ryerson and Wood, 1971, p. 169).

These initial applications were important in establishing the value of aerial photography for agricultural surveys. Air photographs were capable of reducing the amount of time and money required for the completion of a study by as much as five times (McClellan, 1968). They reduced the extent of field work needed, and made it possible to cover much larger areas than could be done by ground survey alone. Furthermore, they made more efficient use of qualified personnel, particularly where such people were in limited supply.

Due to their general suitability, medium scale panchromatic aerial photography and conventional techniques of interpretation, as first used by Goodman, have been widely employed throughout the world for the inventory of agricultural resources. The Canada Land Inventory, for instance, has made extensive use of air photos (McClellan, 1968), as has the United Nations in their programmes in the developing countries of Central and South America, Africa and Asia (Dill, 1967). A more recent example may be cited from New York State, where the Land Use and Natural Resource (LUNR) Inventory is presently being conducted (Crowder, 1972).

Medium scale panchromatic photography is a valuable means of remote sensing, in that it is cheaply obtained, is widely available, and requires no special equipment for interpretation. From most of the studies above, however, it is clearly a means that is also limited in many respects.

For any given date of photography, there is a wide range of images for each crop or land use type, even within the area covered by one photograph. A major portion of this image variation may be explained by the character of the ground surface. Important factors include the farming practices of the individual grower, the growing schedule of the farmer (this is reflected by the degree of maturity of the plant), the condition of the crop, and also the type of soil.

As a second limitation, many different crops appear similar on black and white photography at any given date in the growing season. Over the entire season, however, most crops are highly variable in their appearance, and some are unique at a certain stage of growth. These crops may be distinguished from all others if they are photographed at the correct time. This time varies from crop to crop, and hence, the recognition problem continues to exist.

The similarity of crops on one date of photography also arises due to the nature of the sensor. The panchromatic film as it is conventionally used, responds to a wide range of visible radiation. The image is a combination of photographic characteristics over all wavelengths to which the film is sensitive. As a result, crops which look different on the ground may be similar on the film.

Wood's point about the interpreter's familiarity with his subject is well made. However, it seems that many situations may arise where it is not feasible, financially or temporally, to provide the interpreter with the high degree of knowledge he needs to perform an adequate interpretation. Even a great knowledge of farming will not allow him to overcome all the problems of the individual crop variability or multiple crop similarity that have just been described.

Finally, the medium scale of the photography means that a great many images are essential in an investigation that is regional in scope. For a large area of study, the time and expenses involved become substantial, and the efficiency of the study declines.

2.3 Other Techniques of Remote Sensing

With the potential suitability of air photo interpretation for agricultural studies established, it became apparent that special techniques of interpretation and special sensors might be useful to overcome some of the real limitations of the conventional medium scale black and white photography. There are four categories of specializations that are now employed in crop and land use surveys. These include sequential photography, multispectral sensing, small scale photography, and mechanical image enhancement. At the present time, two or more of these techniques of remote sensing are frequently combined in one investigation; however, they will be separated in the following discussion for the sake of clarity. A fifth specialty, sensing in the non-photographic regions of the electromagnetic spectrum, will not be described, since the method involves different sensing principles and equipment, different types of images, and different factors in interpretation.

2.3.1 Sequential Photography

It was realized early in the agricultural use of aerial photographs that certain crops were more easily identified on one date of photography than on another, but that no single date was ideal for the identification of all crops (Brunnschweiler, 1957). Each crop was found to have a characteristic sequence of images over the growing season; hence, the use of a series of photographs from over the season would likely increase the precision of the interpretation. The values of sequential aerial photography for crop and land use inventory has been verified time and time again, with the use of images from two or more dates for the same fields improving the accuracy significantly (Schepis, 1968; Wood, 1968; Steiner, 1970b; Carneggie et al., 1971; Richardson et al., 1972).

2.3.2 Multispectral Sensing

It is well known that different crops reflect radiation differentially throughout the spectrum,even within the visible wavelengths. Conventional panchromatic photography integrates the reflected light over all wavelengths to produce a single image, and may therefore eliminate most of the differences among the crops. If narrower bands of radiation are sensed, the smoothing effect will be lessened, and these variations may be more apparent.

Photography of narrow bands of radiation is termed multispectral remote sensing, and may be achieved by means of special films and filters. Multiemulsion films may be used to obtain a single image of a ground scene, or various combinations of films and filters may be used to produce a set of photographs for the same scene at one time. With either method, it is possible to sense beyond the visible wavelengths into the near infrared. This is valuable, since it is in the infrared that vegetation is most clearly separated from other surfaces, and that different types of vegetation show their greatest range of radiation reflectance.

The multiemulsion films include the colour and the colour infrared types. The films are composed of three emulsions, each being sensitive to a different band of radiation; hence, a single photograph is a three-band sensor. Early research in the agricultural context compared colour, colour infrared and conventional panchromatic photography, and revealed that the colour infrared film was generally superior (Anson, 1966; Phillpots and Wallen, 1969; Yost and Wenderoth, 1971). Anson noted that it provided twice as much detail and allowed more categories of agricultural land use to be recognized. Today, colour infrared film is used in preference to colour or conventional panchromatic film in most research investigations (Anuta et al., 1971; Brooner et al., 1971; Richardson et al., 1971; Wiegand et al., 1971; Draeger et al., 1972). The same sensing package is also excellent for the detection of crop vigour and disease, which is important in land capability studies and rural planning.

Multispectral photography by means of various film and filter combinations, often referred to in the literature as multibase photography, portrays the ground surface in a series of images of different bands of radiation. The number of bands usually ranges from three to nine, but as many as sixteen have been employed. Investigations by the Laboratory for Agricultural Remote Sensing (LARS) at Purdue University (Anuta et al., 1971; Hoffer et al., 1972), The University of California at Berkley (Carneggie et al., 1971; Thaman and Senger, 1971), and other organizations (Brooner et al., 1971; Wiegand et al., 1971; Mower, 1972) have used three or four bands, and have compared results with those of multiemulsion sensing. One band sometimes produced a unique image for a single crop, but the band varied with crop type or species. Precision was improved by considering the pattern of images through the bands for each crop. By this spectral signature type of interpretation, the level of distinction obtained did not differ significantly from that achieved with colour infrared film. Many authors noted that multibase photographs yielded slightly better accuracy, but that multiemulsion ones were more efficiently obtained and used. It would seem, therefore, that the selection of either one over the other should depend upon the nature of the study, as well as the time, finance, equipment and labour available for image attainment and analysis.

Multispectral sensing in the visible and near infrared regions of the spectrum may be obtained by optical scanners as well as photographic systems. The scanning operation converts the radiation reflected from the earth's surface into an electrical signal, and then records it on photographic film, or on magnetic tape in numerical form. The scanner imagery is of poorer spatial resolution and is less widely available than the photography, but it provides better spectral resolution (there is little or no overlap among the bands of radiation being sensed) and it lacks photographic tone distortion. Much work in the field of multispectral scanning for crop surveys has been carried out by LARS (LARS Annual Report, 1968). Using as many as twelve narrow band images of the same site, they have been able to obtain highly detailed and precise results.

2.3.3 Small Scale Photography

Since 1969, small scale photography from aircraft and spacecraft has been available for civilian use, and has been widely employed in crop and land use inventories on an experimental basis (Eyre, 1971). The small scale yields synoptic coverage for a large area, which is useful for the detection of regional patterns and for the saving of time in interpretation.

Most of the small scale photography that has been used to date has been obtained from NASA space flights. The photography has been combined with other special techniques, including colour infrared, multibase and sequential sensing, and has produced impressive interpretations of crop types and rural land use (Anuta and MacDonald, 1971; Thaman and Senger, 1971; Wiegand et al., 1971).

Very little work has been done in agriculture using high altitude aircraft photography, although the aircraft is clearly more practical than the spacecraft for the attainment of images. It would seem that the recent study by Mack and Bowren (1973) is the only investigation reported to date. These authors used high altitude photographs ranging in scale from 1:60,000 to 1:145,000 to identify rural land use in Saskatchewan. Examining variations in grey tone on red- and infrared-sensitive films, they were able to achieve an accuracy of more than ninety percent.

With the launching of the first orbital Earth Resources Technology Satellite (ERTS-1) in July of 1972, a new type of remotely sensed data became available, that of multispectral imaging at a very small scale of 1:1,000,000. A wealth of investigations of agricultural resources have been conducted since that time (Freden et al. (ed.), 1973; Johnson and Coleman, 1973; Mack and Bowren, 1973; Williams et al., 1973). These have shown ERTS-1 to be most valuable, in that it provides repetative coverage of very large areas, and allows image analysis with improved cost effectiveness and speed of accomplishment (Poulton, 1973). The mapping of general crop type as well as individual crop species has been done by multispectral and sequential means of interpretation and has yielded surprisingly high levels of accuracy.

2.3.4 Mechanical Image Enhancement

A final special technique of remote sensing for agricultural land use is mechanical image improvement, or "spatial filtering", as termed by Steiner (1970a). The technique involves the transformation of the original images into new forms which are more useful and which reveal information not previously apparent.

Colour recombination is a major means of image enhancement employed in agricultural surveys. Three or four separate images are projected through separate colour filters and are superimposed to create one colour composite. Variations in colour are due to tonal differences among the original images. The technique reduces the amount of data to be handled, and also enhances the variations in tone (Yost and Wenderoth, 1971). The combination of multispectral as well as sequential photographs has improved the precision of the interpretation considerably, and in some studies, the sequential combination has been shown to be superior (Carneggie et al., 1971; Thaman and Senger, 1971).

Another method of spatial filtering, that of density slicing, has apparently not been used to any significant degree in crop and land use surveys. Density slicing involves the division of the total range of density on a photograph into a number of classes, and the assignment of a different colour to each class. An experiment in the density slicing of ERTS-1 imagery mapped the distribution of a certain species of plant with notable success, suggesting that the method has the potential to increase the image interpretability for agriculture (Tapper and Pease, 1972).

2.4 Automatic Interpretation

The vast amount of data collected from the specialized sensors has created a pressing need for an automatic means of interpretation. There is neither enough time nor enough personnel to analyse all the photography that is now available. The great number of images involved in multispectral or sequential sensing and in land use inventories of very large areas makes the job of the interpreter long and tedious, and with very small scale photographs, it may be quite difficult. Subtle yet important variations in image density are often not detected, and as a result, the precision of the interpretation is at a lower level than it could be. The demand for automatic interpretation also arises from the need for an objective means of photo analysis. Human interpreters are highly subjective in their work, and any two are likely to produce different results for the same image.

In automatic interpretation, remotely sensed data are analysed by computer; hence, they must be available in numerical form. Image tone or density is the most easily quantified element of the image. While scanner imagery is already recorded in digital format on magnetic tape, photographs must be converted by means of densitometers.

Automatic photo analysis is a problem in pattern recognition. Different land surfaces are recognized from the quantitative information by either the deterministic or the probabilistic approach. With the deterministic one, data are classified generally by clustering. Cellular groupings for different crop types are defined on the basis of mathematical functions (Steiner, 1970b; Richardson, et al., 1971; Su and Cummings, 1972) or the distance to a central value (Wiegand et al., 1971; Richardson, et al., 1971). The probabilistic technique is concerned with the concept of maximum likelihood, such that a piece of rural land is assigned to the class to which it most likely or probably belongs. Probability is determined from various statistical parameters, including the mean and standard deviation, and the frequency of occurrence (Brooner, et al., 1971; Hoffer, et al., 1972; Mower, 1972; Richardson, et al., 1972).

A major problem exists in the automatic interpretation of aerial photography, especially that flown from high altitudes. There is a variation in illumination across the image plane, which may cause two fields that are identical at the ground level to image in different tones on the photograph. Human interpreters may sometimes minimize the density distortion factor by using photographic characteristics other than tone (such as texture or pattern) or by using only limited portions of each photograph. In automatic interpretation, however, the problem will produce misleading results if the quantified data are used directly. The difficulty was recognized almost a decade ago by Steiner and Haefner (1965), who demonstrated that the distortion of tone over a single photograph may be of considerable magnitude. Mathematical techniques have been developed since then to effectively eliminate the problem and these may be used as part of the computer analysis procedure (Bruce, 1972; Hoffer, et al., 1972). From the survey of recently published work in small-scale photography, it seems that relatively few investigators were aware of the tone distortion, or, at least, few attempted to deal with it.

2.5 Summary and Conclusions

In summary, the use of aerial photography for rural land use interpretation began with the analysis of mesoscale panchromatic photographs, and revealed their worth, but moreso their limitations. Of greater value are the more specialized types of remotely sensed data that are now available. These include sequential, colour infrared, multibase and small scale photography, and may be used individually or in various combinations to form a suitable sensing package.

Due to its excellent spatial resolution and its wide areal coverage, small scale photography from space has proven to be valuable in agricultural resource analysis. When employed in conjunction with sequential or multispectral techniques, it provides a most useful sensor for the examination of vegetation on a regional scale. High altitude photography from aircraft has the same assets as the space photography, and it is more easily and cheaply obtained than that from space.

Aircraft photography from high altitudes has been largely unemployed in agricultural studies to date. With this in mind, the current study will use the high altitude aircraft platform in combination with colour infrared film to examine rural land use in the Niagara Peninsula. The photography will be evaluated initially by means of conventional visual techniques of interpretation.

The automatic interpretation of various types of remotely sensed data by computer analysis has been quite successful to date. It is realized, however, that not all investigators have sufficient access to, knowledge of or finances for the compuer assisted handling of such information. The present study will, therefore, attempt a semi-automatic interpretation of crop types using quantified photographic data. The analysis will also involve an attempt to find a simplified means of minimizing the image density distortion that is inherent in high altitude photography.

In the past few years, efforts have been made to improve the precision and efficiency of air photo interpretation through the use of mechanical image enhancement. While the method of colour combination has been extensively utilized, that of density slicing has remained largely untested in agricultural analysis. Density slicing techniques will be of limited value when image density distortion is significant. Since the distortion factor is a prominent one on high altitude photography, the techniques will not be used in the present investigation.

CHAPTER III

NATURE OF THE PHOTOGRAPHY

3.1 Introduction

A basic knowledge of the nature of the image and the imaging system is an essential part of any investigation involving remote sensing. It provides a framework in which to conduct the research. It is important to know the type of radiation that has been recorded and the height from which it has been obtained, in order to realize the criteria and methods required for image interpretation. An understanding of the sources of variation in the image is also useful, since it may help to explain the difficulties and any errors that may arise in the interpretation.

In this chapter, the character of the remotely sensed information used in the current study will be examined. The photographic film and platform (or flying height) will be described in detail, and each will be evaluated in terms of values and limitations. A subsequent section will consider the characteristics of the image obtained from the specialized sensing package that are valuable for photo interpretation. The final part of the chapter will deal with sources of variation in the image, both on the ground and within the imaging system.

3.2 The Photographic Film

3.2.1 Film Details

The photography obtained on each flying mission employed Kodak Ektachrome Infrared Aero film, Type 2443. Developed by the Kodak Company for aerial photographic purposes, this film displays false colours. It is sensitive to the visible and adjacent near infrared radiation, from wavelengths of 0.36 to 0.9 μ.

Colour films are composed of three emulsion layers, each containing silver halide particles that are sensitive to a different region of electromagnetic radiation. The three layers are mounted one on top of each other on a stable polyester base, which minimizes shrinkage, breakage and warping of the film. The stable base is then coated with an anti-halation backing, which prevents the internal reflection of light. Figure 3.1 illustrates the basic construction of a multiemulsion film.

With the colour infrared type of photographic film, the emulsions are sensitized to the green, red and near infrared wavelengths of radiation (Fig. 3.1). All three of the layers have an inherent sensitivity to blue light. This, however, may be eliminated in the process of photography. During exposure, a Wratten Number 12 yellow ("minus blue") or Number 15 (deep yellow) filter is placed in front of the lens to prevent the undesirable blue wavelengths from reaching the film. These filters absorb all incident radiation below 0.50 and 0.52 μ, respectively (see Fig. 3.2).

Processing of the exposed colour infrared film yields colour positive photographs. The colour is produced in each emulsion layer by

Figure 3.1 Construction of the Colour Infrared Film

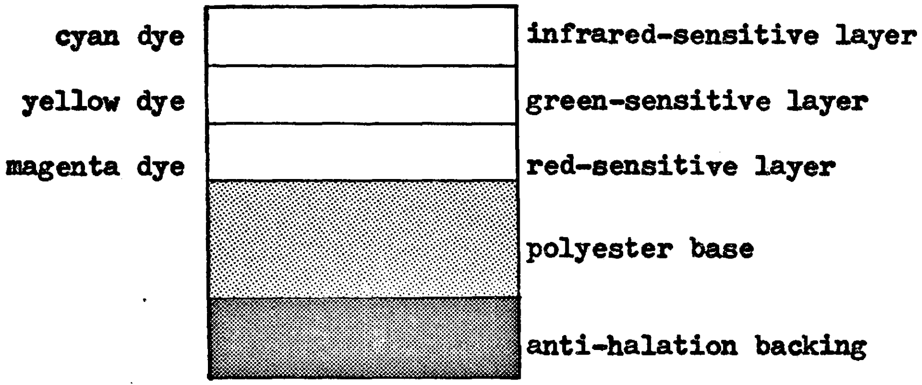
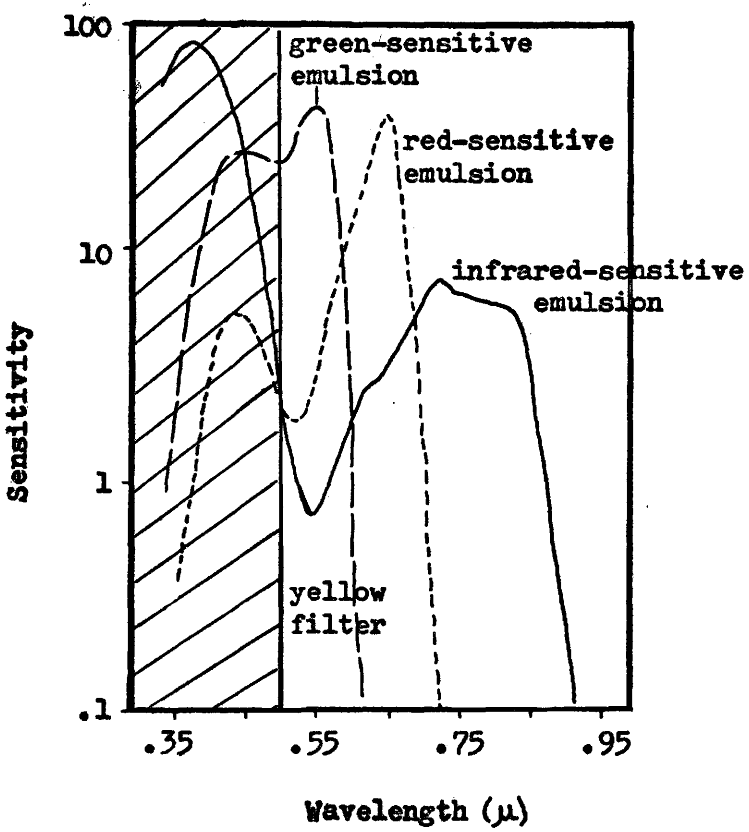


Figure 3.2 Spectral Sensitivity Curves for Kodak Ektachrome Infrared Aero Film



When the Wratten Number 12 or 15 filter is used with the Ektachrome Infrared Aero film, all radiation below .50 or .52 μ is absorbed, leaving the film sensitive to the green, red and infrared wavelengths of radiation.

the technique of dye coupling, whereby each emulsion is compounded with a differently coloured dye. In the case of colour infrared film, the emulsion sensitive to green wavelengths is coupled with yellow dye, that to red wavelengths with magenta, and that to infrared wavelengths with cyan dye. When the film is developed, the dyes effectively subtract their complementary colours from white light, in an amount that is inversely proportional to the degree of film exposure. The green-sensitive layer, coupled with yellow dye, removes blue light, the red-sensitive layer with magenta dye removes green light and the infrared-sensitive layer with cyan dye removes red light. If the exposure is great, then little colour will be removed, but if the exposure is weak, much colour will be removed. The actual colour perceived by the human eye at any point on the photograph depends on the relative exposure of each emulsion layer at that point. Using vegetation as an example, information is strongly recorded in the infrared layer, but poorly recorded in the red and green layers by comparison. As a result, the dyes in the red and green sensitive layers are well developed, removing much green and blue light from the white light, and leaving only red light of the poorly developed infrared sensitive layer to show through. The photo interpreter will therefore observe red-coloured vegetation. Table 3.I presents a summary of the principles of colour infrared photography.

Images recorded on the colour infrared film (or on any other photographic film) may be produced on photographic paper as prints or on clear film as transparencies. The transparency is the more preferred base, since the image quality is superior to that obtained on paper.

TABLE 3.I

PRINCIPLES OF OPERATION FOR INFRARED-SENSITIVE COLOUR FILM

Dominant radiation reflected from object	Blue	Green	Red	Infrared
Film sensitivity with Wratten No. 12 Minus Blue filter	--	Green	Red	Infrared
Dye associated with each emulsion layer	--	Yellow	Magenta	Cyan
Photographic colour of object	Black	Blue	Green	Red

With the print, the graininess of the paper used in the reproduction process reduces the spatial resolution of the image and thus reduces the amount of information available to the photo interpreter.

3.2.2 Merits of the Film

The colour infrared film is a sensing device with many assets, all of which make it a most useful sensor for air photo interpretation studies. This is especially the case in work involving vegetation analysis, such as in the present investigation of rural land use.

Unlike the colour or panchromatic films used in aerial photography, the colour infrared film requires the use of a filter to eliminate the shorter wavelengths of visible radiation (notably, the blue wavelengths). This is most valuable, since it is the blue light that is so easily scattered by molecular particles in the atmosphere to produce haze. The atmospheric haze created by this Rayleigh-type scattering exists between the ground surface and the airborne sensor, and therefore may be recorded on the film at the time of photography. The resultant image will be degraded, with the spatial resolution or detail being less than optimum. With true colour film, the photograph often takes on an overall "washed-out" blue or blue-green tint as a result of haziness in the atmosphere. When colour infrared film is used along with the yellow filter, however, the haze problem is largely eliminated.

Colour infrared film is excellent for the detection of variations in vegetation, since it is sensitive to the near infrared wavelengths of the spectrum. It is in the near infrared band that plants show their greatest variation in radiation reflectance. In the visible part of the spectrum, they tend to be much more similar.

The element of colour in the film is well established as an improvement over the black and white film for photo interpretation. With the conventional panchromatic photography, it is often difficult to detect the subtle variations in grey tone that are important for distinguishing among several surface features. The human eye is capable of discerning only some two hundred different tones of grey. When colour is used,however, many thousands of variations become apparent, since colour has properties of hue (colour of the spectrum,for example, red or green) and saturation (the amount of hue), as well as tone (the degree of lightness or darkness of the image). Interpretation becomes easier and faster, and may also be more precise (Anson, 1966; Carneggie, et al., 1971). In the agricultural context, colour makes it possible to separate fields of young plants from those that are bare, due to the difference in hue; however, both field types are identical in black and white, since they have the same tone.

There are two other aspects of the colour component of colour infrared film, which are of less importance but are nevertheless worth mentioning. For one, the colours that appear on the photograph are generally not natural. Trees are not green and bare soil is not brown. Image interpretation is therefore unbiased by supposed colouring. Secondly, the aesthetic appeal of colour photography is likely of some significance in the process of interpretation. It is suggested that this may be of value when a large area is being examined by a single interpreter.

A final merit of the colour infrared film lies in its construction.

The three-emulsion composition makes it a multispectral sensor. As noted in the preceding chapter, sensing in several narrow bands yields better results in interpretation than does sensing in one broad band. The multiemulsion type of multispectral sensing has some distinct advantages over the multi-camera (or multi-base) method. Images in all three bands may be separated by densitometry, and as the bands are on one film, they are in perfect register. This is especially important for any quantitative work. Secondly, subtle differences in each spectral band are combined and often enhanced in the colour photograph, yet may remain unnoticed when three separate images are viewed. Furthermore, only one camera is required for the flying mission, and only one photograph must be examined for each surface area.

3.2.3 Limitations of the Film

While colour infrared film is an excellent sensing device in many respects, it is also limited in value by a number of factors.

All colour films have a narrow exposure latitude. The critical exposure, (that is, the amount of light permitted to reach the film) has only a small range of values over which it may occur. Consequently, a very precise determination of the exposure setting is essential in order that good quality photography be obtained. When colour infrared film is underexposed, the red of the infrared-sensitive layer disappears, and when overexposed, the red dominates the entire image. In either case, much information about the earth's surface is lost due to incorrect film exposures (Pease and Bowden, 1969).

The processing of coloured film is complicated in relation to black and white processing. The difficulties are reflected in the great variability in the quality of the photographic image. Frequently, there are appreciable differences from roll to roll, and even along one roll (Bruce, 1972). Colour processing differs further from the panchromatic, in that relatively little can be done during processing to compensate for exposure errors. It should be remembered at the same time that exposure errors are much more easily made with colour film than with black and white.

As a multispectral sensor, colour infrared film has a number of restrictions as well as merits. The three bands of radiation that the multiemulsion film photographs are fixed, yet they may not be the most suitable bands for a given interpretation problem. The bands are also rather broad. The information that they record is spread over a range of wavelengths, and this may in fact disguise valuable spectral deviations among various objects.

3.3 The High Altitude Platform

3.3.1 Platform Details

The term "platform" is used to describe the generalized flying height from which remotely sensed information is obtained. Photography that is flown at altitudes greater than normal by means of aircraft, as opposed to spacecraft,is said to be taken from the high altitude platform. The photography produced on these high flying missions is unlike conventional medium or low altitude aerial photography in many ways.

3.3.2 Valuable Aspects of the High Altitude Platform

For the air photo interpreter, the major value of the high altitude platform is the small scale of photography that it provides. It is because of the smallness of scale that each photograph covers a substantial portion of the earth's surface. In the current study, the August photography was flown at 18,000 feet and the September photograph at 31,000 feet above sea level to yield nominal scales of 1:60,000. While the flying height in August was not really a high altitude one, the equivalent of a high altitude platform was produced by means of a superwide angle lens, and each 9 x 9 inch frame covers almost seventy-three square miles. With the large area portrayed on a single high altitude photograph, fewer images are required in an investigation. For a study that is regional in scope, the recognition of and discrimination among various surface features are much simpler tasks when only a small number of images is used.

The high flying height also produces less relief distortion on the aerial photograph. This term refers to the distortion in scale with distance from the centre of the image, which is caused by variations in the relief of the land. The high altitude photographs are more planimetrically precise than the conventional ones, and may actually be quite comparable to a map. This is especially true in areas of relatively low relief, such as the Niagara Peninsula.

From a set of medium scale aerial photographs, it is possible to assemble a photo mosaic that covers an area similar in size to that of a single high altitude image. While it may be argued that the mosaic uses more readily available images, it is decidedly inferior to the high altitude photograph. The composite image may take many hours to make, and its construction can be a rather difficult task. Increased relief distortion at the lower flying height means that only the central portions of the photographs should be used. As a third point, the variation in illumination during photography causes great variability in image tone for similar features and also the same feature on different photographs. Unless the mosaic has been photographically reduced, it will be of awkward size and still of a larger scale than the high altitude image, and if the reduction process has been performed, the image quality will have declined and the expense will have increased.

3.3.3 Limiting Aspects of the High Altitude Platform

The increased distance between the ground surface and the airborne sensing system is responsible for many shortcomings of the high altitude platform.

Radiation reflected from the surface of the earth must travel a greater distance through the atmosphere to reach the high altitude sensor. Consequently, it experiences greater attenuation by molecular scattering than it would with a lower altitude sensor. At the same time, there is an increased vertical distance over which solar radiation may be diffused, producing more interference or noise. The weakened ground information and the strengthened atmospheric noise are recorded together on the photographic film to create an image that is slightly degraded in quality. The spatial resolution of the photograph is reduced, as well as the overall image contrast (the range of tones over the photograph). Degradation of the image is particularly apparent if the shorter visible wavelengths are being photographed, since it is this band of radiation that is most easily scattered by the molecular particles of the atmosphere. The problem may be minimized through the use of colour infrared film, which requires a special filter to eliminate the shorter wavelengths of radiation.

The reduction in the relief displacement, described earlier as an asset of the high altitude platform, is also a limitation. It decreases the stereoscopy of the image, and in areas of relatively low relief, this three-dimensional effect may virtually disappear. With photographs obtained from high flying aircraft, therefore, a property that is generally accepted as important for air photo interpretation is largely removed.

The distortion of image density is a further drawback of photography flown at great heights. This distortion is also present on lower altitude images, but it is only small and usually remains unnoticed. On the high altitude photograph, there is a distinct radial decline in illumination over the image. Further details of image density distortion will be described later in this chapter.

3.4 Elements of Photographic Interpretation

The basic criteria for the interpretation of conventional medium scale panchromatic photography are well established, and can be found in a number of publications. (See, for example, Avery, 1962 or Olson, 1973). In general there are seven elements of the photographic image which are useful for interpretation. These include tone or density (the variations from black to white), texture or the degree of roughness, shape, size (both relative and absolute), shadow and stereoscopy (the variations in height). The final element is object association or the interrelations of two or more images. A simple example would be that cattle in a field indicate its use as pasture. All of these image properties are valuable for the interpretation of agricultural land use on conventional aerial photographs.

When small scale colour infrared photography is employed, many of the standard factors of interpretation are no longer of value. Studies with space photography indicate that much of the detailed information about the earth's surface is lost with the greater platform height, and stereoscopy, shadow and association become largely irrelevant. Pattern and texture tend to remain useful, but they are unlike the pattern and texture observed on the medium scale photograph. As the image scale declines, the image density becomes much more important in the interpretation process.

The specialized sensing package used in the present study introduces a new element for photographic analysis, that of colour. The variations in hue and saturation that are part of colour are valuable, in addition to the variations in tone.

Because relatively few agricultural investigations of high altitude aircraft colour infrared images have been carried out, the aspects of the photograph that are useful for interpretation are not well known. As part of this study, therefore, a strictly visual interpretation of the photography is warranted. Workers with space photography and in other fields suggest that image density is the most important property for the interpretation of small scale photography. To test this hypothesis in the agricultural context, an interpretation based solely upon image density has been conducted as well.

From theoretical considerations and a cursory view of the photography,it is clear that image density is significant for the current problem in air photo interpretation. Variations in image density are the product of a complex set of factors, not merely the variations in the reflectance of radiation from the ground surface. It is essential that this set of factors be examined before any photo analysis is begun.

3.5 Variation in the Image Density

Theoretically, variations in the density of the photographic image are created by spatial variations in the reflectance of solar radiation. On film with an emulsion sensitive to a given range of radiation, two features of the earth's surface will appaer distinct from one another only if they reflect radiation in that band differently, and will appear the same only if they reflect similarly.

This is an ideal situation only. In reality, similar features do not always yield identical images, which serves to complicate the process of interpretation. Part of the variation in image density is inherent in the ground surface. This terrain source of variation actually exists, due to minor fluctuations in radiation reflectance among similar surfaces. There are other sources of density variations that are not related to ground characteristics. These create a distortion of image density, such that the image of a single equally illuminated surface at different points in the photograph will not be uniformly dense. Image density distortion is primarily a product of two factors: the imaging system, and the position of the sun during photography.

3.5.1 Terrain Sources

Almost all types of air photo interpretation are troubled by the natural geographic variability among similar features on the earth's surface. Variability in the image also commonly arises due to differences in human activities. In the agricultural context, these factors cause fields of the same land use to vary in plant vigour and stage of growth, and thus in image density. Natural variability is produced by local changes in the soil and microclimate, while human-induced variability involves different conditions of field maintenance and different dates of similar farming operations.

3.5.2 Image System Sources

The distortion of image density is in part created by the optical construction of the photographic system. The lens of the camera produces an uneven distribution of light in the imaging plane. There is a decrease in the intensity of illumination as the distance from the lens axis increases. The non-uniform distribution is expressed in the density of the photographic image, such that each frame of photography has a pattern of increasing darkness towards its edges.

3.5.3 Effect of the Position of the Sun

The position of the sun during a photographic mission distorts the image density within each frame of photography and also along the roll. In the latter case, the changing solar altitude during the exposure of the film results in changing radiation intensity, and thus changing image density. This has been well demonstrated by the work of Law (1971). On a roll of photography flown over a two hour period in the morning, she observed a continual decrease in the overall density of the image from the beginning of the roll to the end. She noted that the careful processing procedure that was used eliminated the processing as a source of the density decline.

Image density distortion on a single frame originates from the position of the sun as well as the lens system. The solar altitude and azimuth affect the illumination geometry (Bruce, 1972, pp. 68), with altitude affecting the magnitude of the distortion and both affecting the pattern. Both factors cause variation in the radiation reflectance and shadow effects of the terrain, creating a "hot spot" on the land or a sunspot on the water surface. These are centres of low image density, and are roughly elliptical in shape.

3.6 Summary and Conclusions

In this investigation of rural land use, the remote sensing information is provided by high altitude colour infrared aerial photography. The many merits of the sensing package, as described in this chapter, led to its selection for the study. Its small scale provides wide regional coverage on each frame of photography. Its infrared sensitivity makes it especially suitable for the interpretation of different vegetation types. Furthermore, its omission of blue sensitivity practically eliminates the atmospheric haze that is a major problem with the high altitude platform, and therefore provides images of very good spatial resolution.

The interpretation of this specialized type of remote sensing data requires a different set of image properties than are conventionally employed. Finer surface detail is lost at the high altitude, and image density takes on a greater role in the interpretation process. Variations in colour are useful elements of the photography, as are the macrovariations in pattern and texture.

Few interpretations of agricultural land use have been conducted from small scale colour infrared photography recorded from aircraft. Hence, part of this study will consist of a visual interpretation to reveal the elements of the photographic image that are utilized. Since image density is thought to be the most valuable element, an interpretation using solely this property will be undertaken as well.

The value of image density for interpretation is great, yet is somewhat restricted by its variability among images of similar features on the earth's surface. Part of the variation exists in reality, and is related to differences in ground characteristics. Natural geographic and/or human-induced variations occur among similar features, and are recorded by the film. Other sources of variation serve to distort the image density. Lens characteristics and the position of the sun produce areas of lighter density over parts of the photograph, while the changes in illumination with solar altitude affect the overall density of the images along the film roll. Variations in image density tend to be more pronounced on high altitude photography than on the conventional altitude photography, because the increased atmospheric distance from the surface to the sensor decreases the overall density range. With the high altitude images, the three sources of density variations are combined to make photo interpretation a rather complicated operation.

CHAPTER IV

VISUAL INTERPRETATION

4.1 Introduction

As noted earlier in the literature review, to date few investigations of high altitude colour infrared photography have been concerned with the interpretation of agricultural land use, although this sensing package seems ideally suited to such a task. Part of the current project is therefore designed to evaluate the high altitude colour infrared image for rural land use interpretation.

Two areas within the Niagara Peninsula have been selected for study. One lies above the escarpment, south of Grimsby, and the other lies below the escarpment, between Beamsville and St. Catharines (Fig. 4.1). Both areas are primarily rural, and together represent the total of agricultural activities in the northern Niagara Peninsula. The site above the escarpment is largely an area of livestock production, including cattle, horses, hogs and poultry. Crops grown in this region are fodder crops: silage corn, hay crops and small grains (winter wheat, oats and barley). There are many pastures and woodlots throughout, as well as considerable proportions of vacant or fallow land. Any fruit farms in the area are found nearest the escarpment where physical conditions are more suited to this activity. The site below the escarpment lies within the Niagara Fruit Belt. Agricultural land in this region is devoted almost exclusively to vineyards and orchards

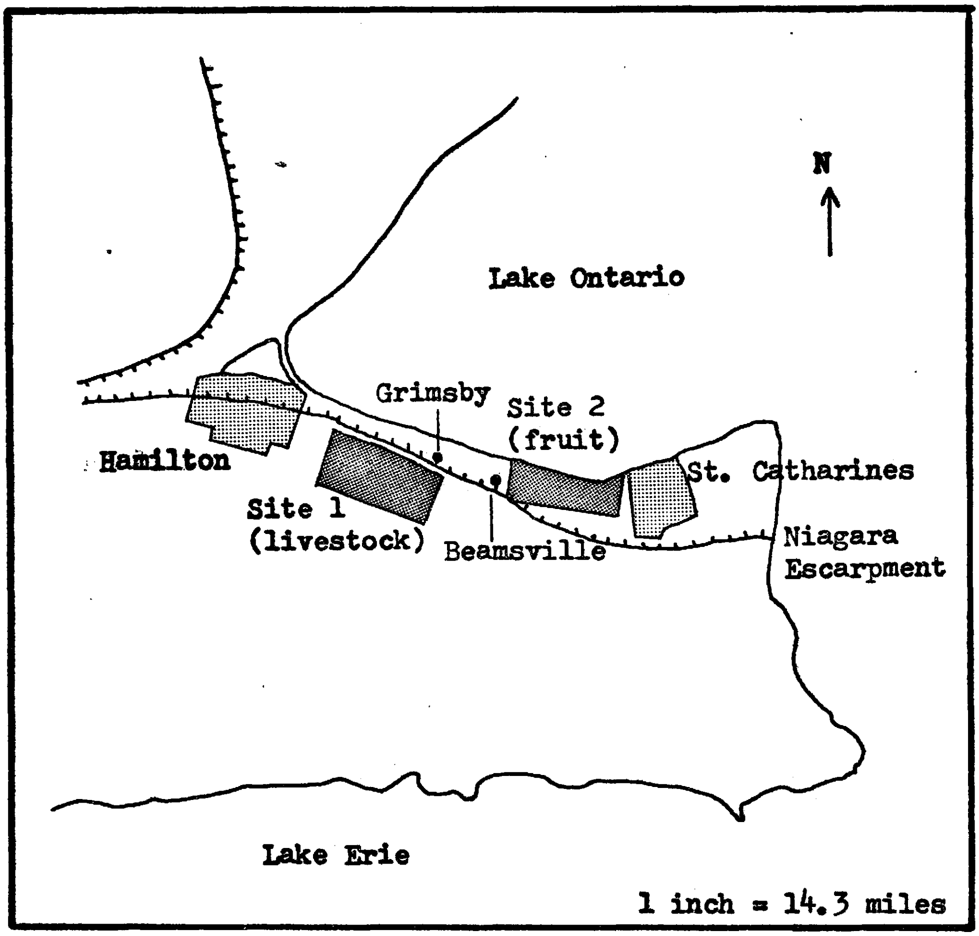


Figure 4.1 Location of Areas of Study within the Niagara Peninsula

(peaches, pears, cherries and plums).

The current investigation has been conducted with three specific objectives in mind. Initially, the elements of interpretation that are useful in the recognition of various rural land uses are determined. Secondly, the amount or level of detail that is attainable from the high altitude colour infrared film is evaluated. As a final problem, photography flown on August 4, 1972 with a 3.5" lens and on September 10, 1973 with a 6" lens are compared, to establish whether one time of year or type of lens is better suited than the other for agricultural interpretation.

In this chapter, the visual interpretation is described in detail. The discussion involves an examination of the attainment of ground information, the procedure followed in the interpretation process, and the results obtained in the study.

4.2 Attainment of Ground Information

On-the-ground studies are an essential part of any investigation involving remote sensing, since they allow the interpreter to learn how a given feature on the earth's surface will appear on the film. They also provide information about the sources and magnitude of the variation that will occur among several images of the same type of feature.

For the present study, ground data were collected on or close to the day on which the photography was flown. This real or near-real time element is critical, especially in the agricultural context where the appearance of various vegetation surfaces may change rapidly with growth or farming operations (for example, harvesting or ploughing).

For the August 4 images, the ground truth was obtained on the fourth and fifth days of the month. For the September 10 images of the following year, it was not obtained until September 28 to 30. This two-and-a-half week delay was unavoidable due to a communications break between personnel at the Canada Centre for Remote Sensing and McMaster University. It was, however, of minimal significance, there being little change in crop appearance and little farm activity over the time period concerned.

The test sites for which the data were gathered lie within the two areas of study described previously. They are outlined in Figure's 4.2 and 4.3. One or more car parties of two people were employed in the data acquisition program, each driving along the roadways and recording roadside land uses on previously prepared work sheets (Table 4.I). Notes were made of field or crop type, as well as crop age, condition, row orientation and undercover where relevant. Any important recent farm operations, such as harvesting, were also recorded. During the observation period, representative photographs of the many land uses were taken for future reference and their positions marked down on the sheets.

It is important to have knowledge of the weather conditions preceding the time of photography, since they will affect the condition of the plants and the moisture content of the soil. For the August 1972 photography, the weather had been warm, with slight rainfall occurring each day for nearly a week before the photography was flown. Most fields had healthy growth and soils were moderately dry. In September 1973, the images were obtained in the middle of a long dry spell with high daytime temperatures. Soils were very dry, and much of the grass vegetation (hay, pasture and fallow) was moisture-stressed

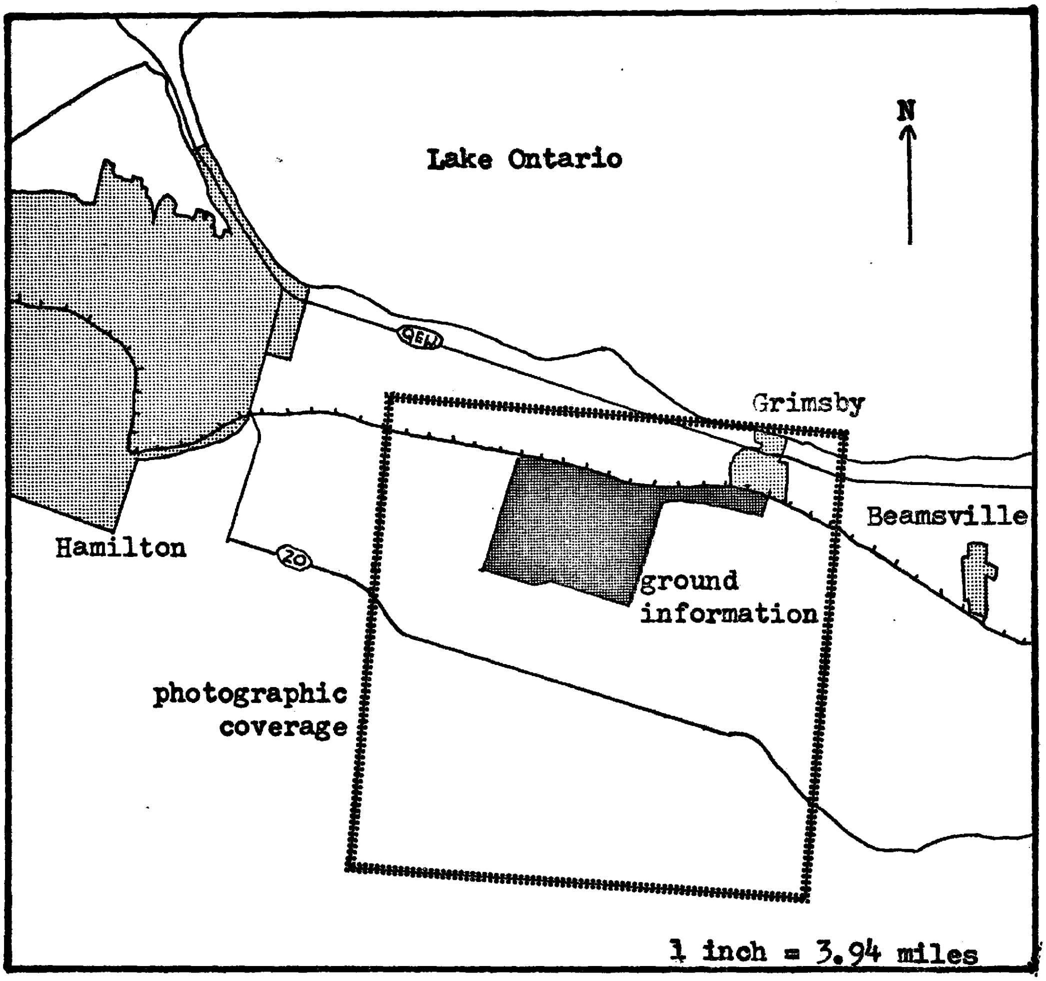


Figure 4.2 Photographic Coverage and Ground Information for Site One

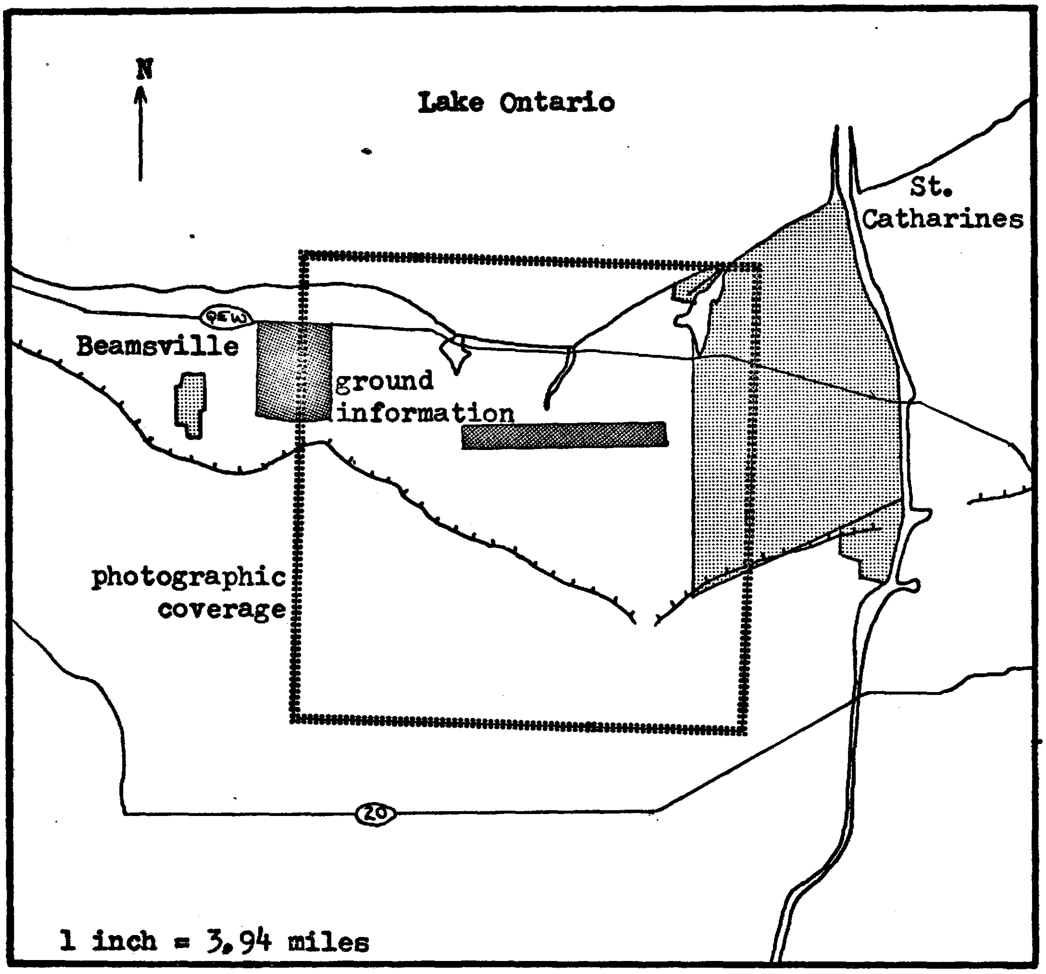


Figure 4.3 Photographic Coverage and Ground Information for Site Two

TABLE 4.I

SAMPLE GROUND INFORMATION SHEET

Date: Sept. 29, 1973
Site: 1

Field No.	Bare Soil	Corn	Small Grain	Stubble	Fallow	Perm. Pasture	Hay	Orchard	Vines	Other	Comments
1				x							brown, short
2		x									yellow, uncut
3							x				cut, brown
4						x					green-brown, photo 13
5						x					brown-green, uneven
6						x					brown-green, uneven
7						x					tall brown
8					x						uneven, brown, rough
9					x						rough, brown, uncut
10							x				uncut, brown
11		x									yellow
12	x										dry brown
13		x									brown, uncut
14									x		mature green, ploughed
15									x		mature green, ploughed
16				x							short, brown, photo 14
17								x			mixed, ploughed
18								x			pear, ploughed
19									x		mature, ploughed
20							x				green-brown, cut

and brown in colour. No frost had occurred prior to the day of photography.

4.3 Procedure

Four frames of photography, two from August and two from September, were selected for the visual interpretation. These were removed from the rolls of film and placed in clear plastic sleeves, in order to protect the emulsions from scratches or fingerprints. (Any such markings would degrade the images and reduce the precision of the densitometry to be carried out later). The frames cover the general areas described in the introduction and include the test sites for which ground information was obtained. Outlined on Figure's 4.2 and 4.3 are the land areas represented on the photographs. Paper prints of the four images employed in this part of the research are presented as Figure's 4.4 to 4.7. The resolution of these prints is somewhat reduced from that of the transparencies actually used, but it is fine enough to allow the reader to appreciate the quality of the photographs.

A preliminary step in the interpretation process involved the construction of base maps upon which land use information could be plotted. Maps of each study area were produced with the Bausch and Lomb Zoom Transfer Scope (Fig. 4.8). This instrument allows information recorded on an aerial photograph to be transferred onto a base map. Mechanical adjustments may be made to remove the planimetric distortions in the photograph and to change its scale,so that it may be fitted to a map base of a given scale. In this investigation, large scale 1:25,000 maps were created from the smaller scale high altitude photography,

Figure 4.4 August Frame of Photography for Site 1
(from Photo no. RS A30486 IR #43)

Figure 4.5 August Frame of Photography for Site 2
(from Photo no. RS A30486 IR #39)

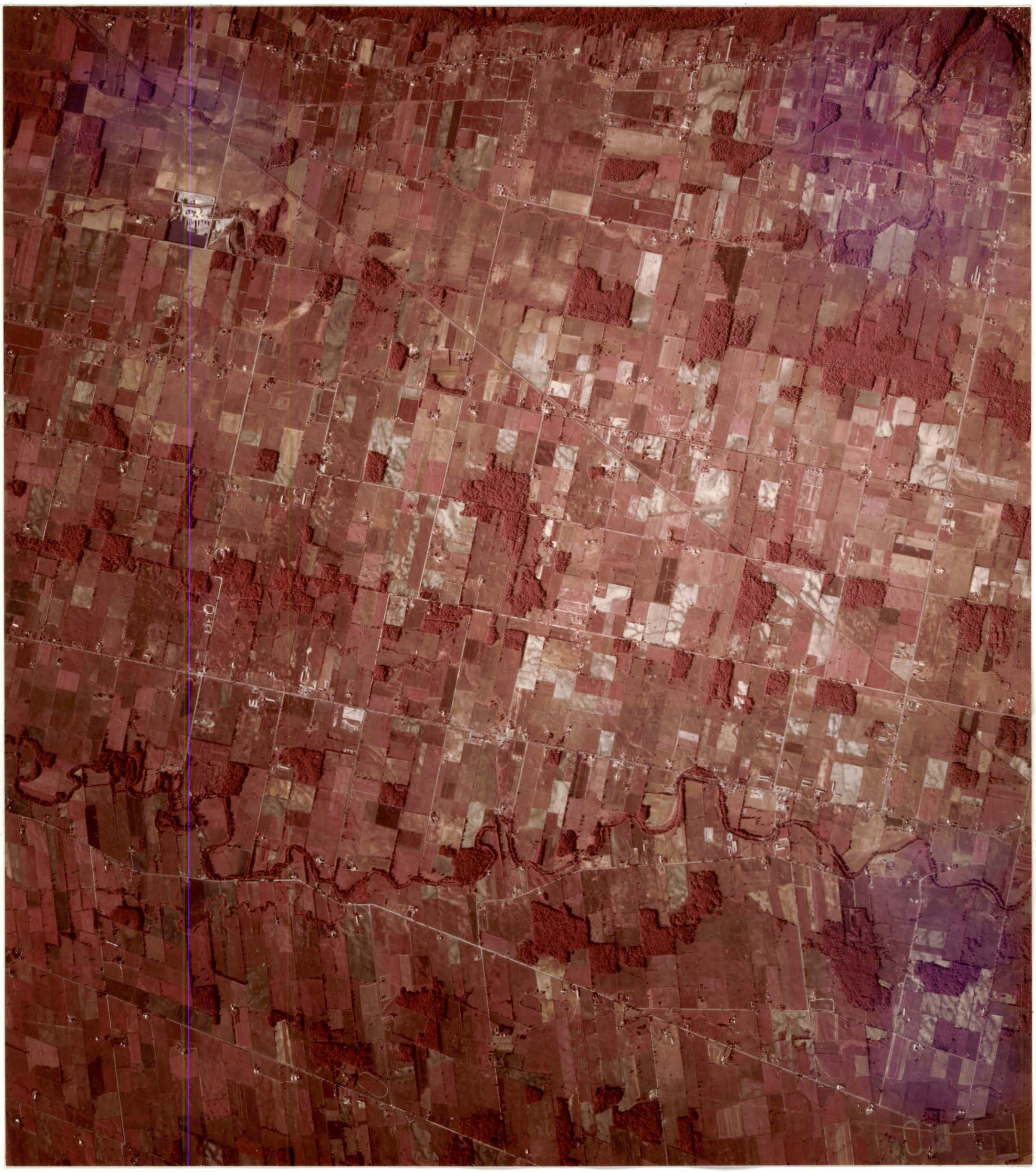


Figure 4.6 September Frame of Photography for Site 1 (from Photo no. RSP A30889 IR #48)

Figure 4.7 September Frame of Photography for Site 2
(from Photo no. RSP A30889 IR #44)

Figure 4.8 The Zoom Transfer Scope

because the photo scale was too small for the interpreter to record land uses within the boundaries of each field.

As a second phase in the visual interpretation, a classification scheme was devised in accordance with known land uses in the area, and was revised following an initial examination of the photography. The system chosen was a numerical one where 1, 2, 3 etc. represent the major groupings, and each of the following digits represents a succeedingly finer division within the major group. Thus, the main class of fodder crops was designated as 2, and within that class corn was designated as 21 and hay as 23. The classification system in its final form is presented as Table 4.II.

The interpretation of the four aerial photographs was carried out using the Richards Light Table with the Bausch and Lomb Zoom 240R attachment (Fig. 4.9). With this optical device, it is possible to magnify the photographic image as many as thirty times and to view adjacent frames at varying levels of enlargement. The photographs were interpreted in such a manner that the same site would not be viewed twice in a row. In this way, the amount of bias in the interpretation was minimized. Each of the photographs was examined in association with the ground information, and the imaging characteristics of the different surfaces in the test areas were ascertained. Land uses throughout the two areas of study were then determined and marked down on the prepared maps by means of their classification numbers. As the interpretation proceeded, notes were made of the criteria used to identify the various categories of land use, and each one was ranked as essential, important but not essential, or apparent but not important.

TABLE 4.II

CLASSIFICATION SCHEME

1	Fruit	11	Vines	110	Young Vines	1100	Young Vines with ploughed undercover
						1101	Young Vines with grass undercover
				111	Mature Vines	1110	Mature Vines with ploughed undercover
						1111	Mature Vines with grass undercover
		12	Orchards	120	Young Orchards	1200	Young Orchards with ploughed undercover
						1201	Young Orchards with grass undercover
				121	Mature Orchards	1210	Mature Orchards with ploughed undercover
						1211	Mature Orchards with grass undercover
2	Fodder Crops	21	Corn	210	Unharvested Corn		
				211	Harvested Corn		
		22	Small Grains	220	Unharvested Small Grain		
				221	Harvested Small Grain		

Continued...

Table 4.II Continued...

		23	Hay	230	Uncut Hay
				231	Cut Hay
3	Uncultivated Land	31	Bare Soil		
		32	Pasture		
		33	Fallow		
		34	Woodlot	340	Dense Woodlot
				341	Open Woodlot
4	Truck Farming				
5	Non-Agricultural Land Uses	51	Farm Buildings		
		52	Non-Farm Rural Residence		
		53	Quarry		
		54	Urban		
		55	Other		

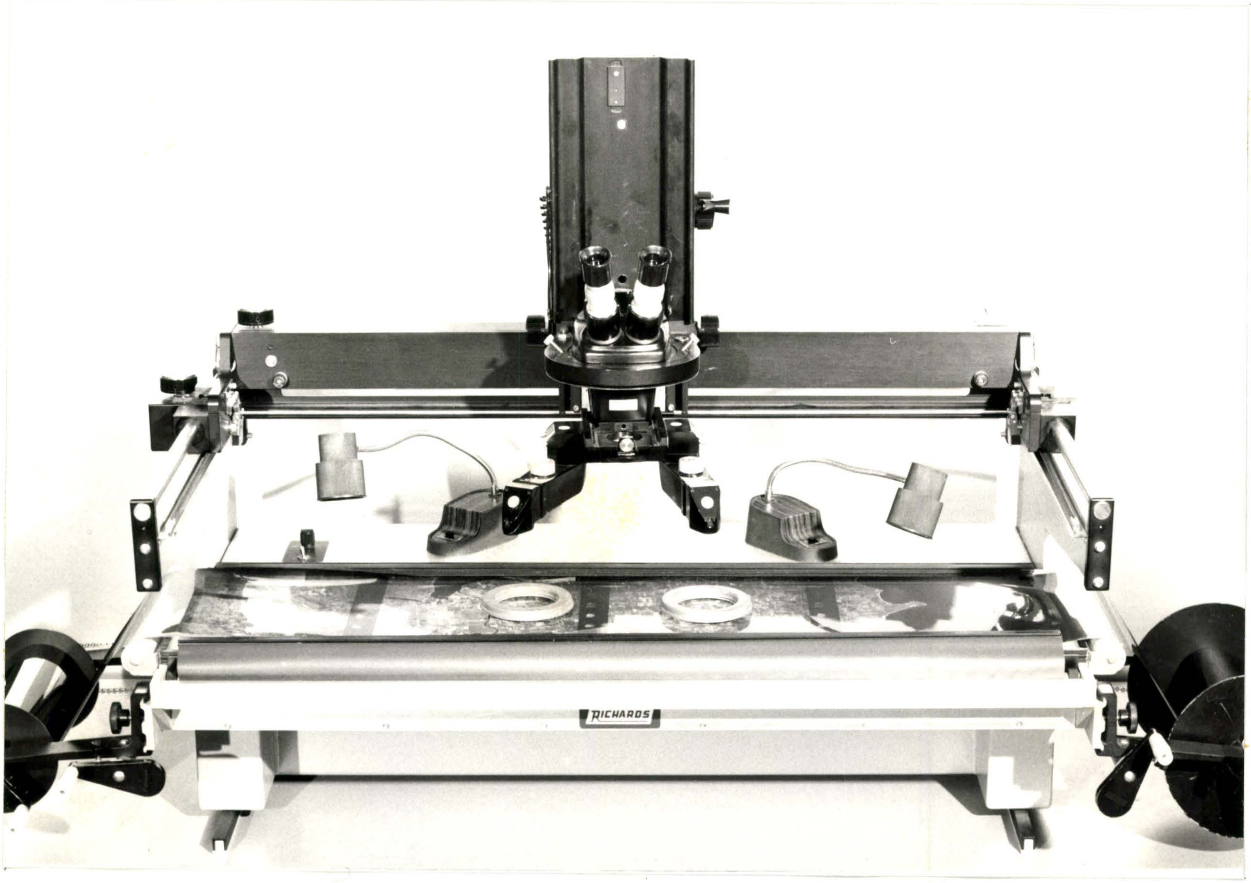


Figure 4.9 The Richards Light Table with Bausch and Lomb Zoom 240R Attachment

4.4 Results

The interpretation of agricultural land use from the high altitude colour infrared photography was a relatively simple task, once the imaging characteristics of the various categories had been learned. For each date of photography, there was a set of distinguishing features for each of the land use classes, and in general, these features were the same anywhere on the photograph. The density characteristic was exceptional, in that the image density of any class increased from the approximate centre of the photograph towards its edges. At any distance from the centre, however, the relative ordering of densities of the different land uses tended to remain the same.

4.4.1 Interpretation from August photography

Figures 4.10 and 4.11 are land use diagrams showing representative areas of Sites 1 and 2, respectively, that have been produced from the August photography. The interpretive elements used to identify each type of land use are described below:

a) Vineyards. These were recognized by their red hue of medium density and their regular, well-defined row pattern. Three subdivisions were evident: young vines in ploughed fields yielded fine, usually discontinuous red lines in primarily light blue fields; mature vines in ploughed fields had a distinctive blue and red linear pattern, with the blue varying in density from light to medium over any one field; finally, mature vines with grass between the rows appeared as alternating rows of light and medium red.

b) Orchards. Areas of orchards were distinguished by their regular crown pattern, their red hue and their high image density. Shadows

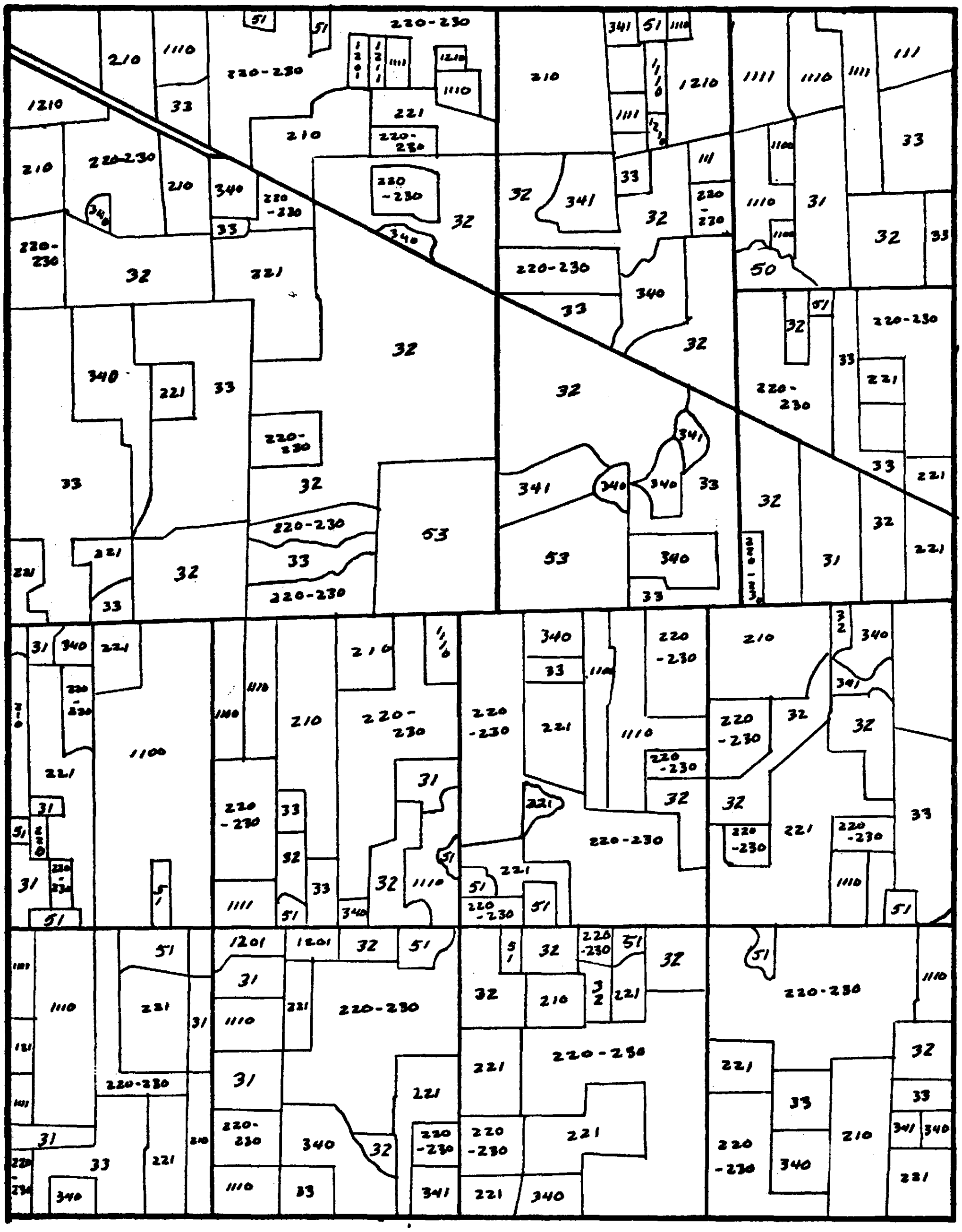


Figure 4.10 August Interpretation from Site 1

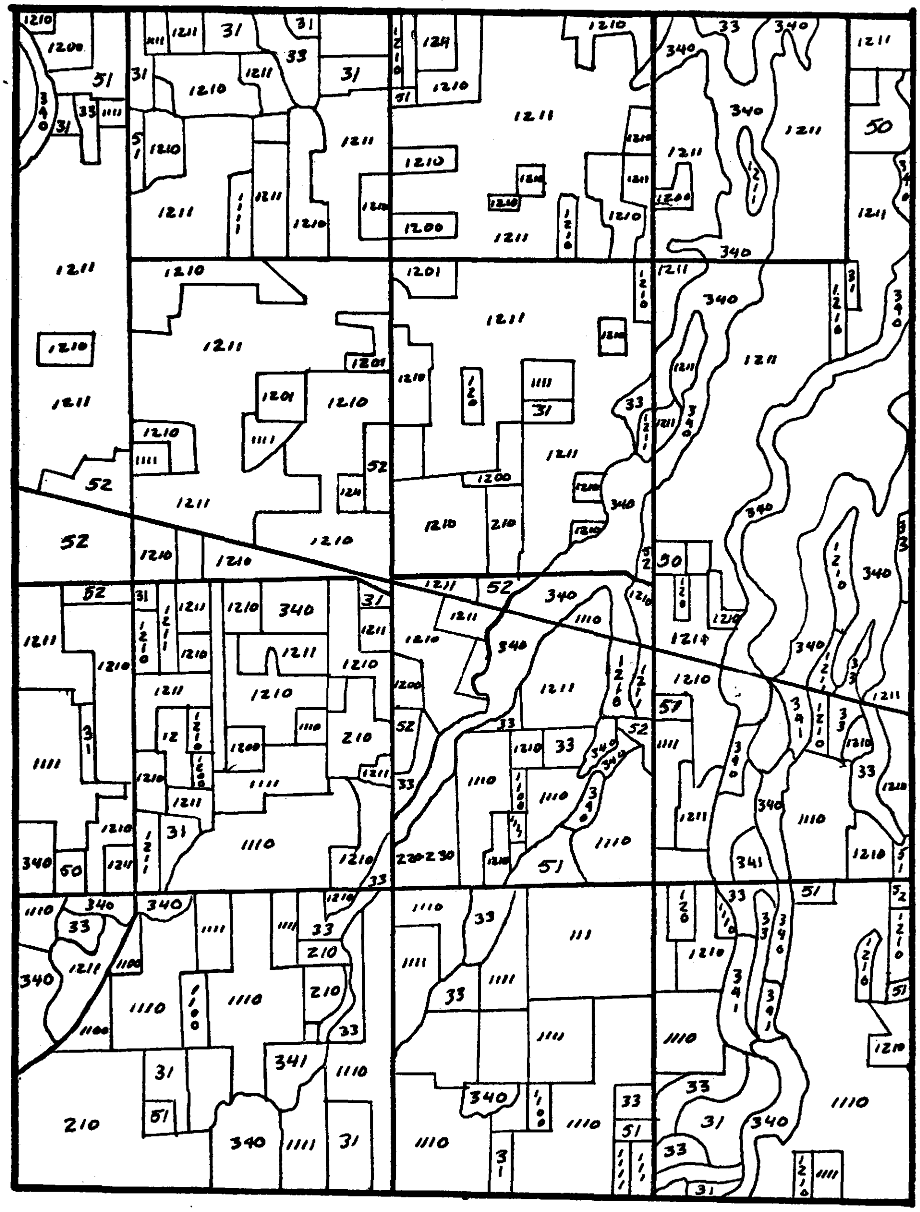


Figure 4.11 August Interpretation from Site 2

were small and insignificant, and stereoscopy was not apparent. Four types of orchards were identified on the basis of their age and undercover. Young orchards had very small crowns in a grid pattern, while mature ones had much larger crowns in a grid or beaded row pattern. Each of these age groups had a ploughed undercover (blue-green in colour) or a grass undercover (medium red in colour) that was visible among the crowns.

c) Corn. This crop produced a deep red image of smooth texture. Occasional strips of bare soil (a blue colour) within the fields were helpful in the recognization of this category, as was the frequently visible linear planting pattern.

d) Hay Crops and Unharvested Small Grains. These were grouped together in the August interpretation. These fields were light to medium red in colour, and often had a wide linear pattern. Drainage patterns were sometimes evident. The lack of distinction is related to limitations in the ground truth, not in the capabilities of the sensing system. Ground information for the August flight was actually gathered prior to the commencement of this investigation for another study. For the upper level, it was limited to the northern edge where fruits are mostly grown, and did not extend back into the livestock area. While various groupings were apparent on the photograph, no specific crop types could be applied to these from the August ground information, and it would be hazardous to infer any crop types from the September data of the next year.

e) Small Grain Stubble. Fields containing small grain stubble could be recognized by their white to green hue and very low image density. Linear or rectangular harvest patterns were often detected, but drainage routes were rarely seen.

f) Bare Soil. This was distinctive on the photographs because of its blue-green hue, low to medium density and clearly visible drainage patterns.

g) Pastures. Areas of pasture land were light red to blue in colour and medium in texture. Drainage patterns were subdued but usually detectable.

h) Fallow Fields. Such fields resembled pastures in hue, but were distinguished from them by their deeper medium density, their coarse uneven texture, and their common patches of bare soil.

i) Woodlots. Trees could be located very easily by their red hue and high image density. The coarse texture and irregular crown pattern further aided in their recognition. Shadows on the north and west sides and stereoscopic vision were present, but were unimportant in the interpretation process. In terms of crown density, woodlots were further classified as dense woodlots, having a solid crown cover, or open woodlots, having irregularly spaced crowns with light to medium red areas among them.

j) Market Graden or Truck Farm Operations. These agricultural activities were occasionally present below the escarpment in Site 2. They were recognized on the basis of pattern, relative size and colour. Small strips of varying shades of red were found in light to medium blue fields. The variable density of the red indicated different crop types; however, no ground information was available to identify them.

4.4.2 Interpretation from September Photography

Examples of the agricultural land use mapping from the September 1973 photography are portrayed in Figure's 4.12 and 4.13. These represent the same portions of Sites 1 and 2 that are shown for August of 1972 in the two preceding illustrations. The image characteristics for the many categories of land use were generally different at this later time of year.

a) Vineyards. These had become a diagnostic deep red or red-brown colour. The distinctive row pattern remained clearly visible, but was less important than in August. Young and mature vines were again separable, but vineyards with grass undercover were less easily detected because much of the grass had died in the dry spell. Fields with bare soil or dead grass had either white or very light to medium blue-green colouring between the rows, while those with living grass had medium red colouring.

b) Orchards. Once again orchards were defined by their regular pattern of deep red crowns. Shadows were apparent on the north and east sides of the orchards, but were not required for identification. As in August, young and mature orchards were distinguished by crown size, and undercover type by hue and density (ploughed undercover was medium blue-green, and grass undercover was medium red).

c) Corn. This crop was easily recognized due to its red hue and medium density, while its smooth thick texture and shadow on the eastern side were also helpful. The linear planting pattern and strips of bare soil that were useful on the August photography were unimportant in September, since the colour properties were so distinctive.

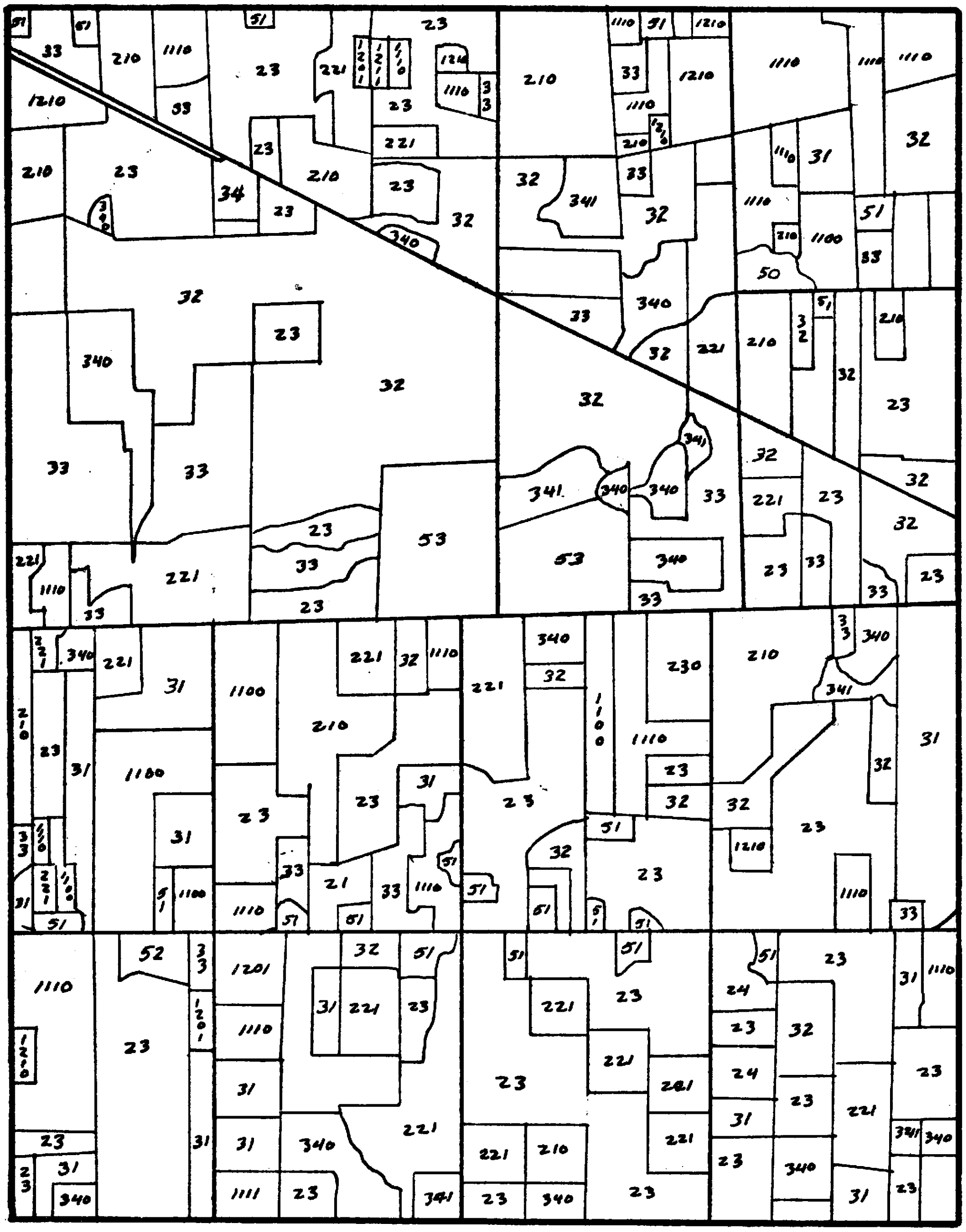


Figure 4.12 September Interpretation from Site 1

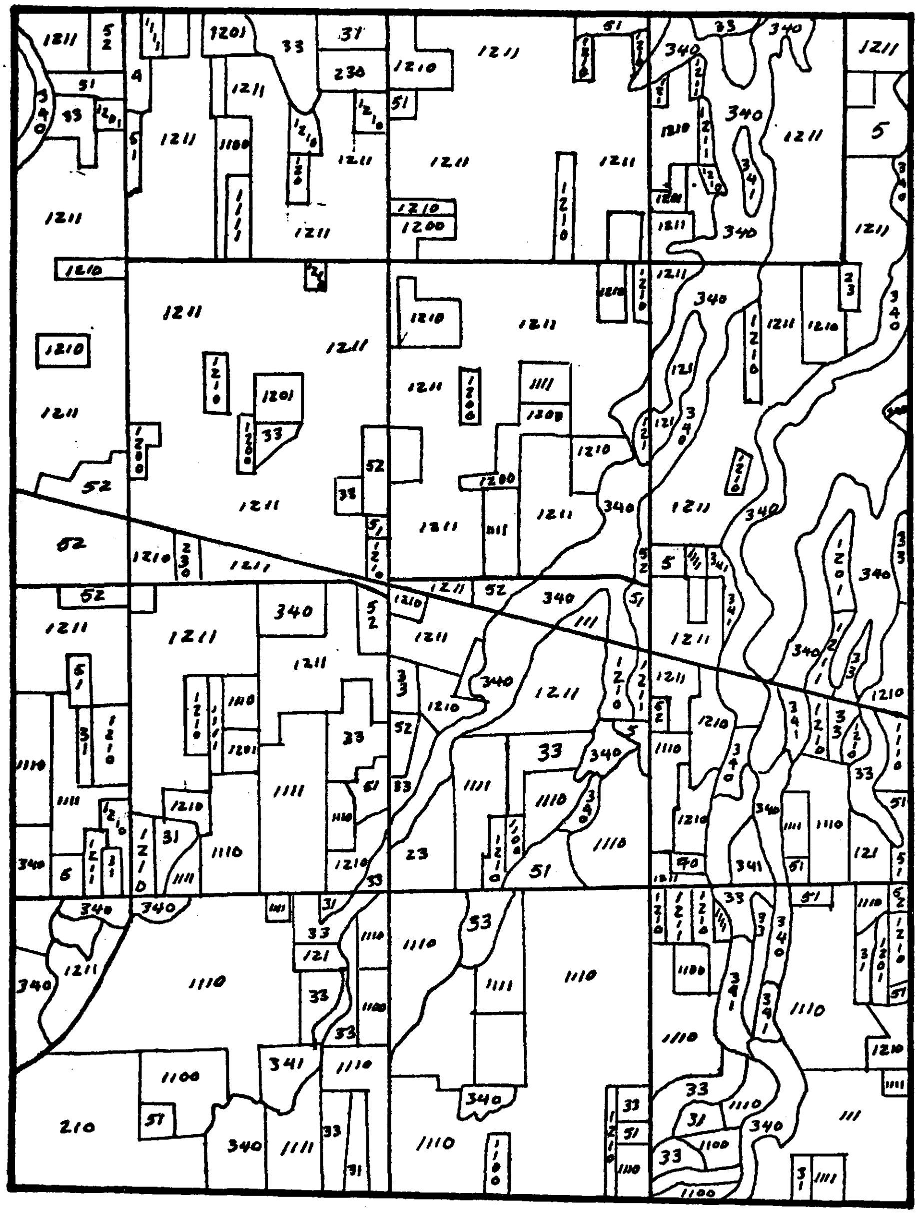


Figure 4.13 September Interpretation from Site 2

Harvested corn was detected by the presence of small portions of uncut corn in other wise white fields.

d) Hay. Fields containing hay ranged in colour from green to red to brown, but could be identified by their medium density, smooth to medium texture, and absence of drainage patterns. Unharvested fields of good quality hay were generally separated from the others by their red to red-brown colour and lack of pattern. The remaining fields were classified as cut hay only if they were green in colour and had a well-defined harvest pattern. Most of the hay fields were not classified beyond the two-digit level, however, due to the high variability of crop quality and time of cutting from field to field.

e) Small Grain Stubble. These fields were distinguished by their low image density and yellow-green to brown hue. Faint drainage and linear harvest patterns were also of value in their recognition. Winter wheat stubble was sometimes apparent, having a yellow-brown colour and wide linear pattern.

f) Bare Soil. Fields of bare soil could be identified very easily. Their blue-green hue and emphatic drainage patterns separated them from all vegetated surfaces. Variations in image density within the field, due to differences in soil moisture content, were useful in the interpretation, but the changing overall field density in relation to that of other land uses made this factor less valuable than hue. A similar situation existed with the August photography of the preceding year.

g) Pastures. These were variable in hue and density, ranging from light red to dark brown and light to medium yellow-brown.

Identification was based on the medium texture, the faint drainage patterns, and the common patches of dead grass, which were a pale yellow-brown. Associated features, especially ponds, were also important.

h) Fallow Fields. Such fields tended to be variable in hue and density as well. They were often similar to pastures in these respects, but could usually be distinguished by their very rough texture, patchy appearance and frequently coarse linear pattern.

i) Woodlots. Areas with trees were readily detected by their high image density and red hue. Some portions of the woodlots had become a very dark brown with the approaching fall season. The rough texture and irregular crown pattern were again helpful in the identification process, but the long shadows on the north and east sides and the stereoscopy were not needed. As before, the open and dense types of woodlots were easily separated on the basis of crown density.

j) Market Gardening. Only one market garden site was located at this later time of year. It was similar in appearance to the August plots, having small red strips of vegetation in blue-green fields of bare soil.

4.5 Discussion

4.5.1 Criteria for Interpretation

For both the August and the September photography, hue and density seemed to be the most important elements involved in the recognition of many categories of rural land use. To give this idea further support, the photographs were examined without magnification and through partially closed eyes. In effect, this procedure reduces the spatial resolution of the images, thereby minimizing the value of pattern, texture and shadow in the interpretation process. It was found that dense woodlots, bare soil, corn and stubble fields could be positively identified on both sets of photography. Mature vineyards could be distinguished on the September photography; however, only mature vineyards with bare soil between the rows were detectable on the August images.

That hue and density are the definitive criteria for the interpretation of several types of agricultural land use has significance for the second part of the current study. In the densitometric study which is to follow,land use will be analysed by means of quantified density information in the three emulsion layers of the film. Since each emulsion is sensitive to a different part of the electromagnetic spectrum, the readings obtained at each point on the film will involve a hue factor as well as a density factor. Only hue and density will be used to identify the various land uses; hence, the quantitative work will provide further grounds upon which these criteria for interpretation may be evaluated.

The original method of interpretation and the subsequent test described above revealed that some land uses, notably orchards, fallow, pasture, hay and open woodlots, were difficult to distinguish by colour properties (hue and density) alone. In these fields, pattern and/or texture were at least as important as hue and density. Even in the categories of land use that were identified solely by hue and density, pattern and texture were found to be helpful in the interpretation process.

The criteria of shadow and stereoscopy were present for only a few types of land use, and were never important in the recognition of these types. Shadows were apparent for the taller crops (corn, orchards, and woodlots), especially in September when the photography was flown late in the afternoon and shadows were long. Stereoscopic vision was possible for the woodlots, but did not exist for the orchards or any other land use.

4.5.2 Resolution of the Photography

For both flying missions, the amount of detail that was recorded on the photographs was impressive. The high resolution capabilities of the film were especially apparent under magnification. Then, it was possible to detect individual tree crowns and individual rows of grape vines in the fruit growing areas. Among the fodder crops, planting patterns were often observed, and harvest patterns of the end-to-end or round-the-field type were easily seen. Variations in soil moisture content or crop growth, due to different drainage conditions over the field, could also be distinguished without difficulty.

On both the August and the September images, the levels of distinction that were possible in the interpretation of agricultural land use were consistently high. With fruit farms, orchards and vineyards were clearly recognized, and each could be further divided on the basis of age and undercover type. Although finer classifications were not made in the present study, they do seem feasible. The recognition of specific types of fruit trees should be possible with a detailed examination of crown size and density. Erb (1967) has done such an identification from medium scale panchromatic photography for the same region. In the case of vineyards, they could likely be analysed in more detail by considering the hue and plant density along each row. For the area of livestock production, fodder crops were classified by crop type and harvested or unharvested conditions, and were separated from various uncultivated land uses. It was found that hay, pasture and fallow produced highly variable images, and were often difficult to distinguish. This problem in interpretation is not really due to limitations in the sensor capabilities. There is in fact a continuum from one group to another, and distinction may also be difficult at the ground level.

4.5.3 Comparison of Photography

It has already been noted that image density was important in the interpretation of agricultural land use, and that its value was limited by its approximately radial distortion over the photographs. While the distortion was apparent on both dates of photography, it was only a major problem in the photography recorded in August. The centres of these images were very light in tone, regardless of land use, and the edges were quite dark. The reduced range of image density at each location made interpretation difficult, especially in the centre. With the September photography, only the extreme edges were limited in their contrast range. The photograph as a whole was quite satisfactory in terms of image density.

The difference in the degree of density distortion between the two sets of photography may be explained by differences in the imaging system and in the time of flying. The effect of the sensing device is due to the use of varying types of lenses for the two flying missions. In August, a short lens of 3.5 inches length was used in the camera. This lens has a very wide angle of view. It causes a marked fall-off in illumination over the imaging plane, resulting in substantial variation in the image density that is unrelated to ground surface characteristics. In September, a longer 6 inch lens was used. The narrower angle of view covered by this lens produces less variability in illumination of the imaging plane. Thus, the distortion of the image density is less severe. The effect of lens length on illumination is well explained by Brock (1970, pp. 24 and 103).

The temporal effect on the level of image density distortion is related to the changing altitude of the sun above the horizon with time. It was demonstrated by Bruce (1972) that as the solar altitude increases, the intensity of the density distortion also increases. At any point on the earth's surface, the solar altitude varies with the time of day and the time of year. In the present investigation, the times of year at which the photographs were taken were already known, and the times of day could be determined from the Greenwich Mean Time (GMT) recorded in the margins of each photograph. Calculations to determine solar altitude involved subtracting five hours from GMT to obtain Eastern Standard Time (EST). The Eastern Standard Time was then corrected for the longitudinal displacement between the areas of study (79° W) and the EST datum meridian (75° W) to obtain True Solar Time.

Knowing the date and true time for each photograph, it was possible to determine the solar altitude from the Smithsonian Meteorological Tables (List, 1966). The results are presented in Table 4.III. These results indicate that the solar altitude at the time of film exposure was greater in August than in September by as much as 37 degrees. This large difference exists because the August photographs were taken closer to the summer solstice and closer to solar noon than the September photographs.

Although the image density over each photograph was distorted, different types of land use usually retained the same relative densities at any point in the frame. Small grain stubble, for example, was lighter than corn in the centre of the image as well as at the sides. The bare soils, however, did not fit this general rule. In September in particular, they were among the lightest fields in the central portion of the photograph, yet among the darkest ones near the edges. Their deviation from the usual case is thought to be due to the type of light reflectance from the soils as opposed to the vegetated surface. The bare soils were generally quite smooth, and light falling on such surfaces is reflected in a mirror-like or specular manner. The vegetated surfaces, on the other hand, were much rougher, due to varying plant height, the spaces between the individual plants and the flexible plant parts that move in response to wind. As a result, the reflectance of incident light is of the diffuse type, where it is scattered outward in all directions. With the diffuse reflection from the vegetation, the amount of light reaching the camera is potentially the same anywhere in the imaging plane. With the specular-like reflection from the bare soil, less light is available at the sides than in the central region.

TABLE 4.III

IMPORTANT SOLAR PARAMETERS IN IMAGE DENSITY DISTORTION

Date of Photography	Area of Study	GMT	EST	TST	Solar Altitude
August 4, 1972	1	16:01	11:01 A.M.	10:45 A.M.	62°
	2	15:57	10:57 A.M.	10:41 A.M.	62°
September 10, 1973	1	9:24	4:24 P.M.	4:08 P.M.	25°
	2	9:21	4:21 P.M.	4:05 P.M.	25°

Thus, the bare soil registers in a relatively darker tone towards the edges of the photograph. The effect of variable ground reflectance from bare soil is enhanced by the radial pattern of image density distortion. Thus central fields become very light and lateral ones very dark.

The difference between relative densities of vegetation and bare soil was more consistent in September than in August. In September, all soils were very dry, and two separate plots imaged the same in any part of the photograph. In August, however, there was no drought and the soils exhibited varying moisture contents. Since the colour infrared film is sensitive to moisture differences, bare soil images were often of variable density even within a limited distance on the film.

Variations in hue were important in distinguishing among the many classes of land use in September, with colours ranging from red to green to brown. On the August photography, however, almost all of the vegetated surfaces were red. Land use interpretation was more difficult at this earlier period in the growing season, because the variations among the different types were more subtle. The demand placed upon the interpreter's ability was greater, and the time required for the interpretation was longer. Furthermore, some categories that were distinctive in September could not be separated in August. Vineyards with grass between the rows were occasionally mistaken for unharvested for unharvested fodder crops, and hay or small grains sometimes closely resembled corn.

Based on this discussion of image density distortion and hue variability, the September photography was selected over that of August as being more suitable for the interpretation of agricultural land use. Although the high altitude colour infrared sensing package was used for both sets of photography, they were obtained with different types of lenses, at different times of day and at different times of year. In the case of the September images, these three factors were combined in such a way as to minimize the image density distortion and maximize the hue variability. As a result, the identification of various types of rural land use was faster, easier and somewhat more precise with the September set of photography.

It is hypothesized that these simple observations on the nature of the image density distortion and hue variability on the September and August photography will also be apparent in the densitometric study that is to follow. When hue and density are quantified in this later work, the results should substantiate and more clearly define the patterns suggested by the visual interpretation.

4.6 Summary and Conclusions

The investigation thus far has shown that high altitude colour infrared aerial photography obtained from aircraft is a most valuable sensing package for the interpretation of agricultural land use.

The colour properties of the film, notably, its hue and density, were very important in the identification process. In many cases, crop recognition was possible by these factors alone. The variation in colour among the different types of land use was especially great later in the growing season. At this time, the interpretation could be more easily carried out.

The spectral sensitivity of the film was a second factor making it useful for this study. The recording of reflected near-infrared radiation on the film produced vastly different images for the various surfaces. Also important was the insensitivity of the film to blue light. The haziness produced by these shorter wavelengths was not a feature of the photographs. As a result, the images were of fine quality and high detail.

Although the photography was at a much smaller scale than is conventionally used, its resolution remained very high. Textures and fine patterns were easily seen and were valuable in the identification of various types of agricultural land. The level of distinction was most impressive, and was greater than required for many types of land use mapping.

The high altitude platform permitted wide areal coverage on each photographic image, which proved to be another helpful element of the sensing package. The interpretation was easy and efficient, since it was unnecessary to continually change the photographs being examined. The construction of the base maps from the high altitude photographs revealed that the planimetric distortion on each image was small. Thus, the mapping procedure was not difficult, and the photographs gave the interpreter a realistic view of the ground surface. The reduced relief distortion due to the high altitude minimized the stereoscopy for the different types of land use, but this factor was not needed in the interpretation process.

The amount of detail and level of distinction for the various types of rural land use was comparable to those of sequential medium scale panchromatic photography, with which the author has also had experience. The high altitude colour infrared package was preferred for many reasons, all of which made the interpretation easier and faster. For one, a single photograph replaced many for any given date. Secondly, one date replaced many dates; hence, one photograph replaced a whole series of photographs covering the growing season. A final point is that the element of colour added an aesthetic quality of the images, which made the interpretation more pleasant and less monotonous.

The one limitation of the sensing package that became apparent in the investigation was the image density distortion over the photographs. Areas of severe distortion had a reduced contrast range, which reduced the resolution of the film and, in turn, its suitability for interpretation.

From the comparison of the two sets of photography, it is concluded that colour infrared film flown from high altitudes will be of more value for agricultural land use mapping when a long lens is used and when the exposure is made late in the growing season and early or late in the day, rather than when a short lens, mid-season and mid-day exposure are used. The preferred conditions result in greater image variation between the different land uses, less image density distortion and, therefore, better interpretability.

The findings of this work have significance for the second part of the research, which will employ quantified hue and density information from the film. The importance of hue and density in the human interpretation suggests that a quantitative analysis will also be possible. The numerical data should show the image density distortion as well, and may permit it to be minimized or eliminated by mathematical means. Thus, the visual interpretation discussed in this chapter provides a sound and logical basis for the work that is to follow.

CHAPTER V

DENSITOMETRIC ANALYSIS

5.1 Introduction

It has been established from the visual interpretation that hue and density are important criteria in the recognition of agricultural land use from high altitude colour infrared aerial photography. The second phase of this project involves a semi-automatic interpretation using these two factors alone. Measurements of photographic density in the green-, red-, and infrared-sensitive emulsions and in the film overall are obtained by densitometric means and are then used for a quantitative analysis of rural land use.

The four density readings collected at each point of the photograph are examined to reveal their usefulness for the identification of different types of land use. Their distribution over the photograph is also studied, in order to indicate the degree and pattern of the image density distortion that is inherent in the sensing package.

Since the relative density distortion in each layer of the film should be the same at any point on the photograph, it is hypothesized that the ratio between any two of the density readings will eliminate the distortion problem. Various ratios are determined and are then analysed in terms of their ability to remove the distortion and to separate different classes of agricultural land use.

This discussion of the semi-automatic interpretation considers first of all the collection of quantitative information from the photography, and secondly the methods used in the analysis of these data. The results are then presented and compared to those of the visual interpretation.

5.2 Data Collection

Before any quantitative analysis could be done, numerical values of image density had to be obtained from the film for different types of rural land use. The recognition of the various land uses for this part of the study was based on the visual interpretation described in the previous chapter. Large samples of each class were identified, and fields were selected to give as even and unclustered a distribution over the photograph as was possible. These steps were necessary to permit a meaningful statistical analysis of image density distortion to be carried out. The actual point selected for densitometry within each field was chosen to be representative of the field as a whole, and any irregularities which would complicate the analysis were avoided.

Due to the limitations in the time and scope of this project, it was not feasible to examine all categories of land use that were recognized in the visual interpretation. Classes which had only a small number of representatives, which were identified on the basis of pattern, or which were very inconsistent in hue and density, were considered unsatisfactory for densitometry, and were therefore omitted. There were four categories of land use which had a characteristic hue and/or density and which were thought to be ideal for this part of the study.

These included bare soil, woodlots, corn and stubble fields. Vineyards were also considered useful due to their distinctive colouring, but preliminary investigations revealed that variations in the type of ground cover and the amount that was visible made density readings highly variable. Furthermore, many fields were too small for densitometry, and their restricted areal extent made them unsuitable for the analysis of density distortion patterns. In consequence, vineyards were not included in this phase of the project.

Values of image density for the four selected classes of land use were obtained from the site above the escarpment (Site 1) for the August and the September photography. Two overlapping frames were used for each set, in order to assist in the evaluation of the ratio technique of interpretation.

5.2.1 Densitometry

The Welsh Densichron densitometer was used to quantify the image density recorded on the film.

The densitometer is an instrument which records the optical density of the photograph; that is, it measures the amount of light transmitted through the film transparency. As can be seen in Figure 5.1, the densitometer consists of a rectangular metal box upon which is set the photograph, an attached arm which houses the sensing device, and a separate meter which provides a reading of image density.

The basic mechanical operation of the densitometer may be described in the following manner. When the power switch is turned to the "on" position, a light source in the metal box directs white

Figure 5.1 The Welsh Densichron Densitometer

light towards the viewing plate on the upper surface of the box. The film transparency is set on top of this viewing plate, with its emulsion side up to avoid scratching. An aperture in the plate allows a beam of light from the source to pass through a portion of the film. When the probe arm is drawn down, the sensing head comes to rest on the film surface directly over the aperture and measures the amount of light passing through the film at that point. Since variations in density may occur within the area of film being sensed, the densitometer provides an integrated value of image density. This measurement is then indicated by a moving needle on the logarithmic meter scale, where 0.0 indicates zero density (100% transmission of light) and increasing values indicate increasing density.

The aperture of the densitometer is of variable diameter, and may be changed simply by replacing one aperture disc with another. For the present study, an aperture diameter of 2 mm was selected. This size was small enough to cover the area within most field boundaries, yet was large enough to provide a density value integrated over most of the field. In this way, the value recorded gave a mean image density for each field. Smaller apertures were avoided, since they would decrease the amount of light available to the sensing head and, in turn, the range over which the density readings were spread. The aperture discs are available in either black aluminum or translucent plastic. The black ones were used for this project, however, in order to reduce the interference caused by overhead room lighting.

As discussed in an earlier chapter, the colour infrared film records information in three emulsion layers, each being sensitive to a different range of radiation. The image density in each range may be different due to spectral variations in the reflectance of light from the ground surface. With the densitometer, it is possible to measure the density recorded in each emulsion by means of a set of filters. Located between the light source and the aperture, each filter allows only light of certain wavelengths to pass through; hence, the film density in only those wavelengths will be measured by the sensing device.

Four different filters were used in the present investigation, corresponding to Positions 1, 2, 3, and 4 on the densitometer. These are Wratten gelatin filters, numbers 92 (red), 99 (green), 98 (blue) and 106 (amber), respectively. The amber filter is a visual density filter for colour film, and is used to measure the density of the colour infrared film as seen by eye. The red, green and blue filters have spectral transmission characteristics similar to the three emulsion dyes of the film, and can therefore be used to measure the density recorded in each emulsion layer.

The electronic design of the densitometer is such that image densities recorded through all four filters are relative to one another. By a system of attenuators, the densities through each filter are all zeroed to a common base before any measurements are made. The variations in readings from filter fo filter are thus comparable, and are indicative of variations in spectral reflectance from the ground surface.

Several precautionary measures were taken to ensure the maximum precision possible in the readings. For one, the instrument was factory serviced prior to use, in order that it would be dust free and functioning efficiently. Secondly, the densitometer was allowed to warm up for at least one half hour before any readings were taken, because the warming of the gelatin filters causes significant changes in the zero values. Minor fluctuations may occur up to four hours later; hence, the densitometer was frequently checked during use and rezeroed when necessary. A further precaution involved the collection of measurements in subdued light conditions to minimize the interference by strong fluorescent lighting in the room. Fourthly, cotton gloves were worn to protect the film from fingerprints, and care was taken to avoid scratching it. Each frame was stored in a plastic shield when not in use to further guard against unnecessary dust and scratching. These would distort the readings of image density. To ensure that the readings were made at the exact locations desired, one final step was taken. Acetate overlays were attached along one side of each frame, and transferrable dots with the same diameter as the aperture of the densitometer were placed over the points to be used. The frame and its overlay were positioned on the viewing plate so that the dot filled the light opening. Then, the overlay was lifted while the frame was held in place, and the probe arm was lowered to make the readings. Measurements were made through all filters without moving the frame, in order to keep them in register with one another.

5.2.2 Digitization

Because computer programming would be used in the analysis of the raw densities and the ratio technique, the point locations where the density values were obtained also had to be quantified. The x and y co-ordinates of the dots on the overlays were determined by means of a Ruscom-Logics Digitizer (Fig. 5.2). With this instrument, the co-ordinates of each point in reference to a specified origin were recorded directly on computer cards. The four readings of image density for each point were punched onto the appropriate cards, and the data were then ready for analysis.

5.3 Method of Analysis

Three prepared computer programmes were used to analyze the values of image density collected from the four categories of land use on each photograph. Initially, the ratios between two readings were determined. Six ratios were produced for each point, namely ratios of the red to green, red to blue, red to visual, green to blue, green to visual and blue to visual filters.

For each category of land use on the various frames, the raw densities and the ratios were processed with one of the BIOMED statistical programmes to calculate some elementary statistical parameters. These included the minimum and maximum values in each group of data, the range of values that occurred, the mean, the standard deviation and the standard error of the mean. These figures were used to examine the variability within each class and among the different classes of land use for the two sets of photography. To assist in the examination, the range of values within one standard deviation of the mean were graphed for the various sets of data.

The third stage in the analysis of the data involved the use of

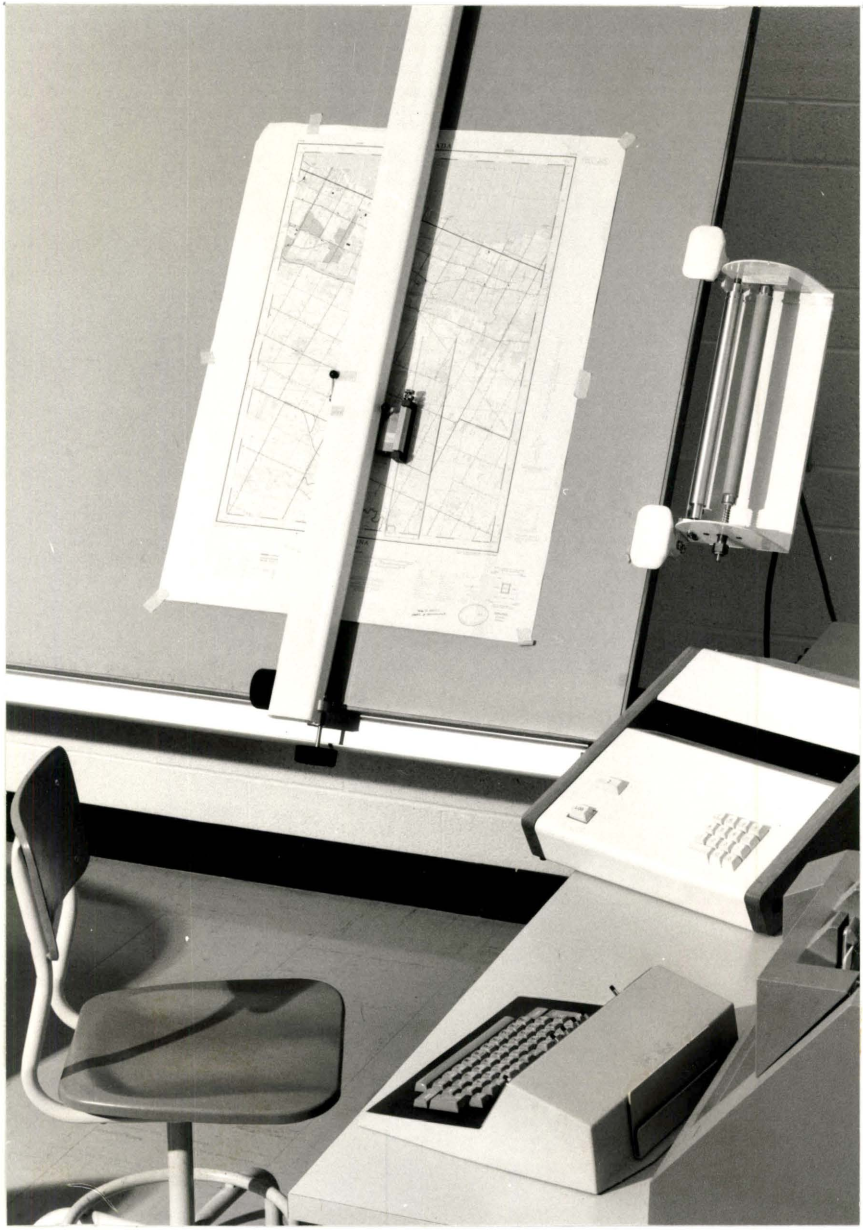


Figure 5.2 The Ruscom-Logistics Digitizer

a trend surface programme with the raw density and ratio values. This was done to examine the nature of the image density distortion in the original photographs and the extent to which the ratios would remove it. The programme calculated first, second and third order trends and residuals for each group of data, and produced photo-sized plots of each. The trend surface plots were presented as choropleth maps, with different symbols being used to designate the many classes of values in each group.

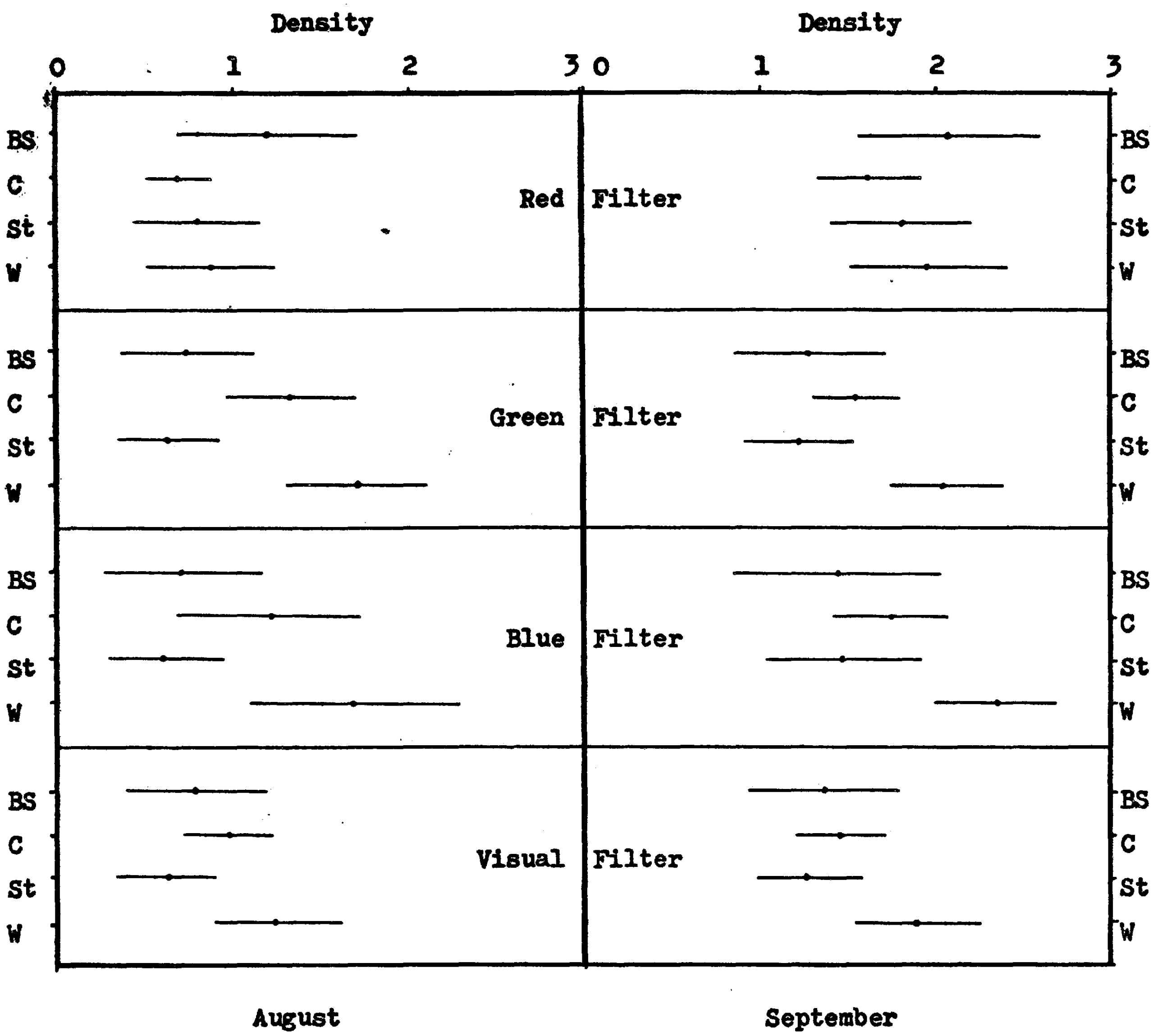
5.4 Results and Discussion

5.4.1 Raw Densities

Readings of image density through all filters were highly variable for each type of land use, as can clearly be seen in Figure 5.3. The great variability was present on the August and the September photography, and covered a similar range of values for the two frames used on each date.

The variations in density for each land use extended over a somewhat greater range of values in August than in September. This was indicated by the statistical parameters as well as the trend surface analysis. The same situation was apparent in the visual interpretation, and was explained by variations in the illumination of the imaging plane between the two dates. Greater variations in ground characteristics in August are also thought to be important, since the trend surface did not fit the data quite as well at this earlier time in the growing season.

Figure 5.3 Variability of the Original Density Readings



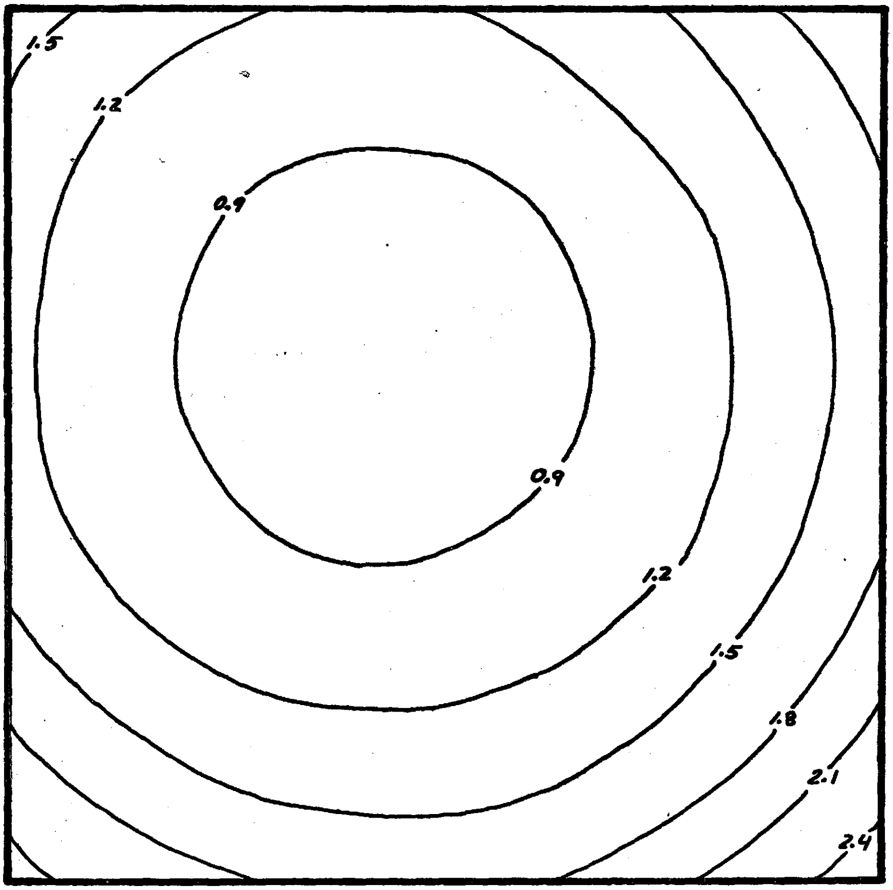
Graphs show the range of values within one standard deviation of the mean image density (.) for bare soil (BS), corn (C), stubble (ST) and woodlots (W).

Different ranges of values were observed on the two dates of photography. In September, the readings were greater overall than in August, indicating a darker image density in response to decreased illumination. The readings obtained through the red filter in particular were darker. This is likely due to the decreased infrared reflectance from vegetation at the end of the growing season, since a similar degree of darkening in the red filter values was not observed for fields of bare soil.

A greater variation in density was apparent for bare soil than for other land uses. Its minimum values were among the lowest recorded for all land uses, and its maximum values were among the highest. This supports the observation made in the visual interpretation, that bare soil did not maintain the same relative ordering of density among the various classes of land use over the photograph.

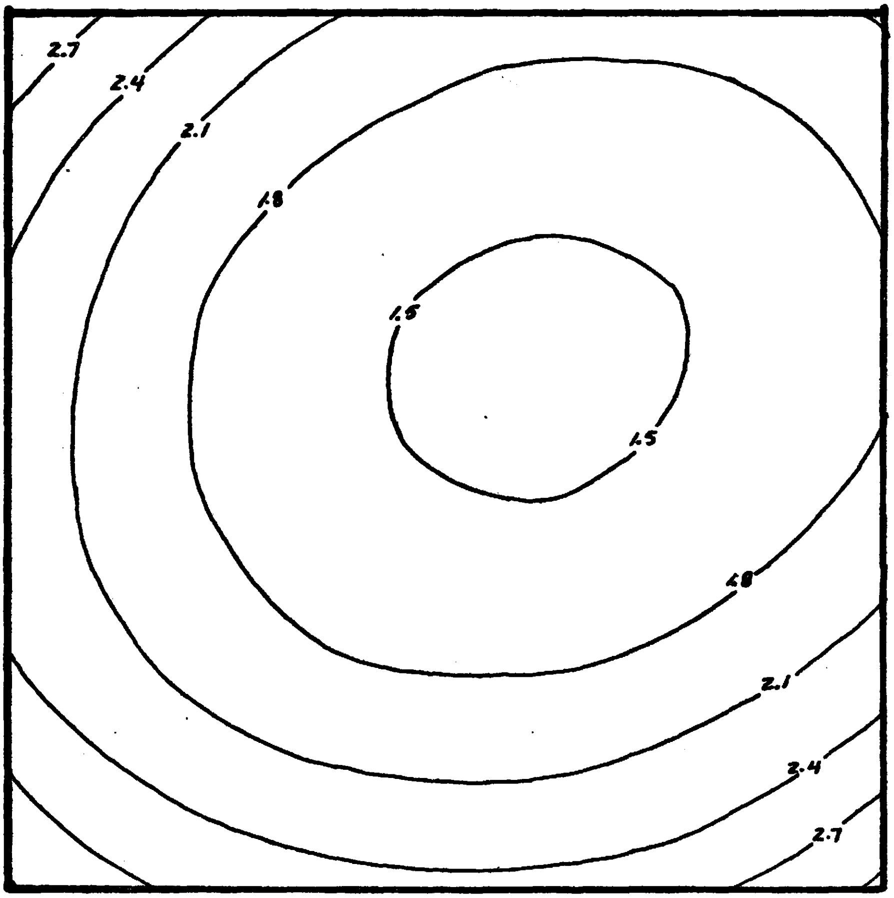
The second order polynomial trend surface described the pattern of variation in image density over the photograph very well. In general, it explained at least 80% of the variation. The first order surface fitted the data very poorly, while the third order surface did not significantly improve the level of explanation. Figure's 5.4 and 5.5 are presented as examples from the August and the September photography. These illustrations clearly show the approximately radial pattern of increasing density that was noted in the visual interpretation. The region of lowest density was round or elliptical in shape in all cases but the bare soil on one of the August frames. In this instance, the small sample size and poor point distribution were thought to cause the anomolous pattern, since it was not observed on the adjacent frame

Figure 5.4 Second Order Trend Surface for Visual Density in August



Isolines join points of equal image density through the visual filter for woodlots.

Figure 5.5 Second Order Trend Surface for Visual Density in September



Isolines join points of equal image density through the visual filter for woodlots.

where the sample was more suitable.

In comparing patterns of image density variation for the August and the September photography (Fig.'s 5.4 and 5.5), it can be seen that the orientation of the pattern varies, although the general radial effect is maintained. In August, the region of lowest density is slightly west of the centre of the photograph, but in September, it is considerably east of the centre. The same orientation occurred on all sets of data from each date, and was also detected in the visual interpretation. It is an effect of the differing illumination geometry at the time of photography on the two dates.

The degree and pattern of variation in the readings of image density were roughly similar for all filters, all land uses, all frames and both sets of photography. In consequence, it is clear that the ground surface is not the main source of the differences in image density. The pattern is characteristically that of the image density distortion produced by non-uniform illumination over the imaging plane (see Law, 1971; Bruce, 1972). For each land use, over 80% of the variation is explained by the density distortion factor, leaving only some 20% to be explained by the natural variability at the ground surface.

For the purposes of land use identification, clearly the great variability of the density readings for each type means that the raw density values alone are of little use. The wide range of values even within one standard deviation of the mean resulted in considerable overlap among the different land uses, which made differentiation very difficult (see Fig. 5.3).

While the readings through no filter could be considered suitable for land use interpretation, some were better than others. It is evident from Figure 5.3 that the red filter was the worst of all for the distinction of different types of vegetation, although it was somewhat better for the separation of vegetation from bare soil. The green filter seemed to be the best to distinguish among vegetation types, followed by the visual filter and then the blue.

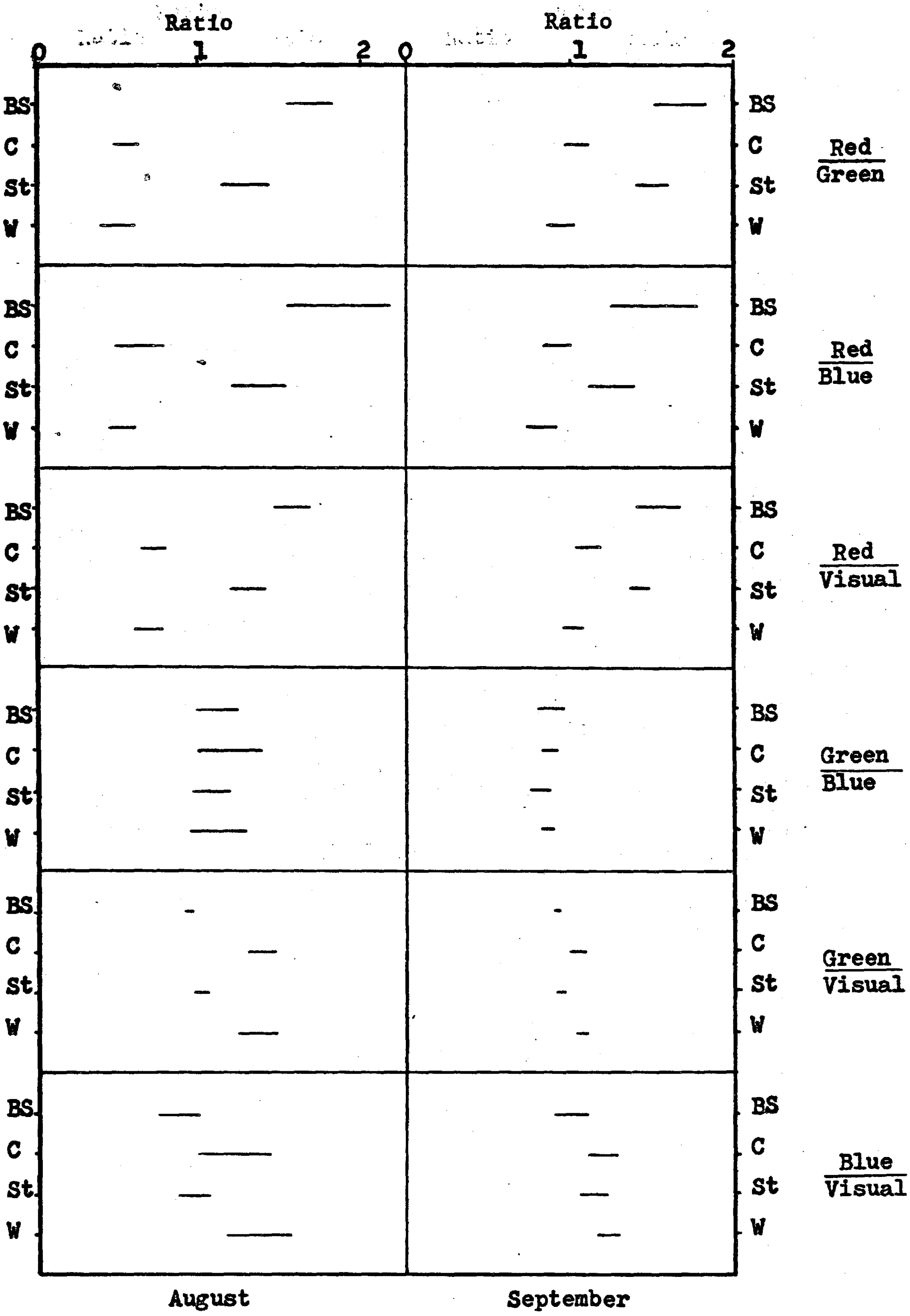
Considerable differences in the mean value of image density occurred for the various categories of land use. Thus, fluctuations in reflectance for different surfaces were recorded on the film, and the density values may be useful for interpretation if their variability were reduced. This suggests that the ratios between the filters, calculated to minimize the variations in density readings for each land use, should be more valuable than the raw densities in the interpretation process.

5.4.2 Ratios

The various ratios calculated for each land use were much less variabile than the raw density readings from which they were determined (see Fig. 5.6 and compare to Fig. 5.3). The reduced range of values was characteristic of both the August and the September photography. As with the raw densities, the ratios for any one land use were the same on the two frames of photography from each date, but were different in August than in September.

The range of values covered by each ratio tended to be greater in August than in September. This was also noted in the raw density

Figure 5.6 Variability of the Ratios



Graphs show the range of values within one standard deviation of the mean ratio for bare soil (BS), corn (C), stubble (ST), and woodlots (W).

readings, and is in part due to the greater variation in surface reflectance at the earlier time in the growing season.

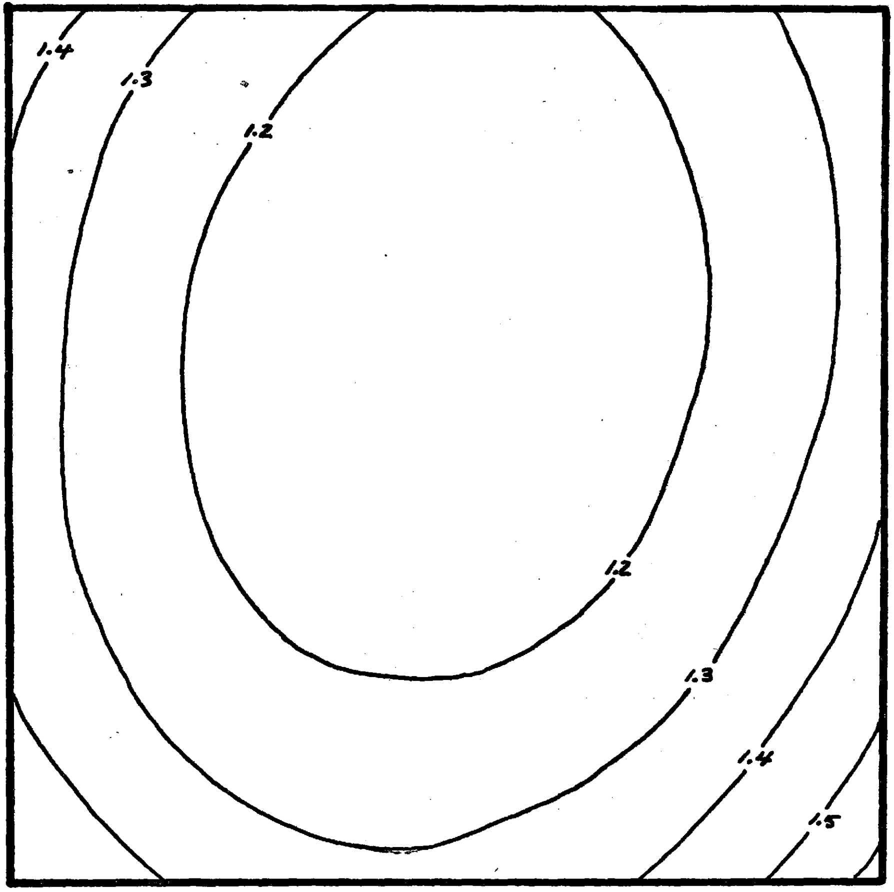
The decrease in variability occurred in different amounts for the different classes of land use, as can be seen in Figure 5.6. In September, the ratios for bare soil were generally the most variable, but in August, there was no consistent relationship between the land use and the degree of variability. The same situation was present with the raw densities, with greater variation being in the category of bare soil. Hence, the ratios also show the effect of differences in the type of radiation reflectance between the smooth bare soil and the rough vegetation surfaces. The ratios in August did not show the same pattern, since the effect of the more variable surface reflectance for each type of vegetation was comparable to that of the differences in the reflection of light between soil and vegetation.

The second order trend surfaces that were fitted to the data explained much less of the variability that they did with the raw densities. Even when the third order surface was examined, the degree of explanation was not greatly increased. Sample plots from August and September are illustrated in Figure's 5.7 and 5.8. The radial image density distortion pattern is again apparent; however, the intensity of the distortion is very much reduced.

The second order trend surfaces gave a markedly higher level of explanation with some categories of land use than with others. Corn and stubble were consistently low (less than 40%), whereas bare soil and woodlots were consistently high (greater than 60%).

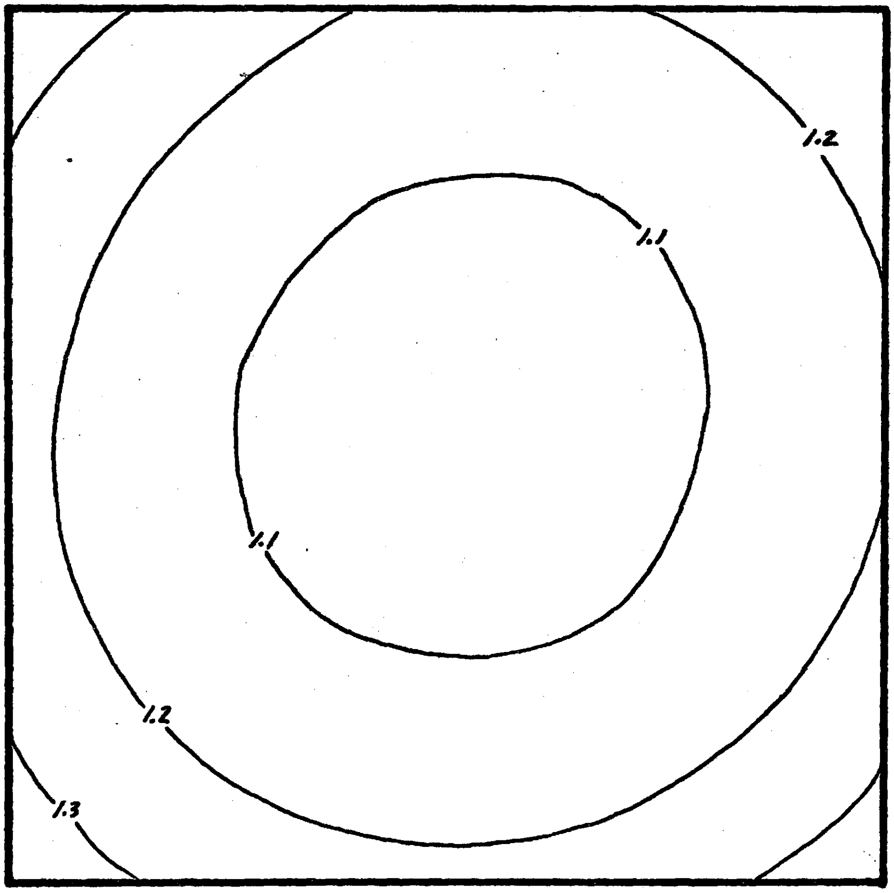
The reduced range of variation and the reduced level of

Figure 5.7 Second Order Trend Surface for Green to Visual Ratio in August



Isolines join points of equal ratios of the green to visual image densities for woodlots.

Figure 5.8 Second Order Trend Surface for Green to Visual Ratio in September



Isolines join points of equal ratios of the green to visual image densities for woodlots.

explanation indicate that much of the image density distortion was removed by the ratio technique. The distortion was, however, not fully eliminated, suggesting that the hypothesis of equal density distortion in each emulsion of the film was incorrect. This seems to be the case with bare soil and woodlots moreso than with corn or stubble.

The decreased variability of the ratios in comparison with the raw densities is valuable for the identification of various types of land uses. Examining Figure's 5.3 and 5.6, it can be seen that the differentiation among the land uses also is clearer with many of the ratios than with any of the raw densities. A further point in favour of the ratio technique is made by the fact that the ratios are similar on two frames of photography from the same flying mission. This suggests that the ratios may be derived for one frame, and then may be applied to several others if the exposures are made over a fairly short span of time.

Some ratios seem to hold more potential for the interpretation of agricultural land use than others. It could be argued that the green to visual ratio is the best, since the variability within each land use class is least; however, the values for all land uses together are spread over a very narrow range, and would likely make their separation difficult (Fig. 5.6). The ratios involving red filter readings of image density, especially the red to blue ratio, seem to be more promising. These have somewhat greater variability within each type of land use than the green to visual ratio, but they are spread over a significantly greater range of values when all land uses are considered. Preliminary attempts at the recognition of land uses, conducted in the previous summer, also suggested that the red to blue ratio might be the best in the interpretation process. The green to blue and the blue to visual ratios are of little value for interpretation, there being a high degree of similarity in values for the different categories of land use.

5.5 Summary and Conclusions

The quantification of the image density recorded on the film has substantiated the observations made in the visual interpretation regarding the nature of the density distortion over the photograph. It has shown that the degree of distortion is intense when a high altitude platform is used. This causes considerable overlapping in the values for different types of rural land use, making the raw densities largely unsuitable for the distinction of the various land uses.

The calculation of the ratios between the two readings of image density in different emulsion layers of the film significantly reduced the degree of density distortion. Hence, the ratio technique makes the density factor more useful in interpretation. For rural land use recognition, the ratio of densities in the red and blue emulsions seems to hold the greatest potential. The red to green ratio also seems to be of value, contrary to the findings of Mack and Bowren (1973).

This investigation of the ratio technique has been of a preliminary and superficial nature only. Since the technique holds promise as a simple interpretive tool, several recommendations are made for its further analysis. A statistical testing of the precision of the ratios for the recognition of different types of rural land use would provide strong grounds upon which the method could be assessed. This should be done for the green to visual ratio and the three ratios involving the red filter readings, since these seem to be the better ones, and should be extended to other types of land use besides the four used in the current study. It is also recommended that a consideration of the pattern of variation from ratio to ratio be made for the interpretation process. (For example, using the red to green, red to blue and green to visual ratios in that order, one land use may have high, high and low values for the respective ratios, but another land use may have low, high and low values).

CHAPTER VI

SUMMARY AND CONCLUSIONS

6.1 Summary

It was noted in the literature review that many different types of remotely sensed information have been used in agricultural studies, but that high altitude aircraft photography has remained largely unemployed. There is a need for the evaluation of this seemingly useful sensing package, by visual as well as automatic techniques of interpretation.

Considering the nature of the photographic package, the colour infrared film and the high altitude platform have been combined to produce a potentially valuable sensing device for the analysis of agricultural land use. This type of photography covers broad areas of the earth's surface, has very fine resolution capabilites and is especially suited to the detection of differences in vegetation. The small scale should preclude the use of many of the conventional photographic elements for interpretation and should increase the importance of the element of image density. The major drawback of the high altitude platform is presented by the distortion of image density that is a product of uneven illumination in the imaging plane of the camera. This is due to the lens characteristics and the position of the sun during photography.

The visual interpretation confirmed the expected value of high altitude colour infrared photography for the recognition of rural land use. The amount of detail and the levels of distinction attainable were more than sufficient for most agricultural surveys. Of the conventional elements of interpretation, shadow and stereoscopy were rarely apparent and were not needed for crop recognition when they were. The hue and density factors were the most important in many cases, although texture and pattern were also of value. In the visual examination of the photography, the density distortion could clearly be seen, and made the interpretation very difficult when it was severe. The September photography was selected over the August photography for its suitability in crop recognition, since the density distortion was less intense and there was a greater range of hues for the different land uses at this later time in the growing season.

The densitometric analysis fully supported the findings of the visual interpretation regarding the image density distortion over the photograph. It revealed that the density factor alone could not be reliably used for an automatic (quantitative) interpretation, because the great variation in values for each land use made them all very similar. When the ratios between two readings of image density were determined, the variability was significantly reduced, and the density factor in this modified form became much more useful for interpretation. The green to visual ratio was the most successful one in eliminating the distortion, but the red to blue ratio seemed to give the greatest differentiation among the various categories of land use. The fact that no ratio completely removed the distortion suggests that not all emulsion layers were affected equally by the variable illumination of the imaging plane.

6.2 General Conclusions

The use of high altitude colour infrared aerial photography flown from aircraft is highly recommended for the interpretation of agricultural land use. To minimize the degree of image density distortion recorded on the film, the photography should be obtained with a lens of long focal length (for example, a 6 inch lens as opposed to a 3.5 inch lens), at a fairly late time in the growing season, and either early in the morning or late in the afternoon.

The calculation of the ratio between the image densities recorded in two emulsion layers of the film effectively reduces the degree of density distortion. This step requires quantified remotely sensed information, which take a very long time to obtain from photography by mechanical hand-operated means. If the ratios determined from these data must be examined by hand in order to identify features of the earth's surface, then it would be better to avoid any quantitative work and use conventional visual interpretive techniques. It has been shown in this study that such a procedure yields fine quality results, as long as the density distortion factor is realized and the interpretation done accordingly.

If, however, the ratios are analyzed by computer and the object recognition carried out by automatic means, then the quantification procedure is justified. In this case, the interpretation may be conducted quite rapidly, especially when large areas must be considered.

The present investigation also showed that different land surfaces possess different degrees of density distortion over the photograph. This point had not be previously established.

6.3 Recommendations for Further Study

Since the investigation of the ratio techniques has been of a superficial nature, a number of recommendations may be made for further study.

It is suggested that a computer analysis of the ratios be done, in order to establish the level of precision attainable in the automatic classification of rural land uses, and to establish whether one ratio is better than the others in the classification process.

The ratio technique should be extended to different land uses than were used in this study. This would determine whether the method is generally applicable, or whether it is suited to only a few types of agricultural activities.

Other dates of photography should be examined as well, especially in June or July when there is a greater variety of crops in the fields. If the ratio technique proves useful for the identification of different grain crops, it may be of value for extensive agricultural areas that are less readily accessible than the Niagara Peninsula, notably the Prairie regions of central Canada.

Finally, it is recommended that the ratio technique be tried with other procedures in remote sensing. A quantification of the photographic density by microdensitometry, whereby a series of lines is scanned across the photograph, would permit values of image density to be obtained more rapidly than by the point densitometry used in this study. The ratio technique should also be tried with multispectral scanner data. This remotely sensed information may be directly recorded in numerical form on magnetic tape; hence, it requires no quantification. While it is realized that the density distortion of aerial photography is not apparent in scanner imagery, the ratio technique should still be useful. It reduces the range of values and amount of information that must be examined for each type of surface.

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